Weeds

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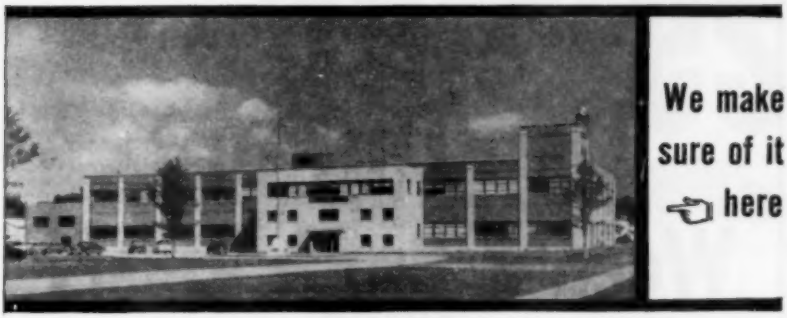

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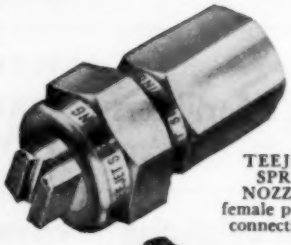

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Weeds

JOURNAL OF THE ASSOCIATION OF REGIONAL WEED CONTROL CONFERENCES.

VOLUME III JULY 1954 NUMBER 3

Control of Aquatic Weeds That Impede Flow of Western Irrigation Waters*

EUGENE T. OBORN, *Plant Physiologist*

INTRODUCTION

CROP PRODUCTION on most lands of the western United States requires the use of supplemental water which is delivered through established irrigation canal distribution systems. These systems frequently support heavy growths of aquatic plants which prevent or impede the passage of water. Because a reduction in the carrying capacity of a canal makes it necessary to deprive potential productive land of the water required to grow a satisfactory crop, it is imperative to keep the waterways open.

This report, evolved from fundamental as well as applied and developmental research, describes certain pertinent investgations which suggest improved and more effective field techniques to accomplish a solution of the problem at hand. It also summarizes the highlights of a number of studies on different phases which will be published soon in more comprehensive form (11, 12, 13, 14). Selected references pertaining to work of other investigators have been included in the Bibliography.

Because of recent widespread success of certain phenoxyacetic acid derivatives on land weeds, the effect of these and other herbicidal compounds on obnoxious submersed and emergent aquatic weeds was deemed worth investigation. To this end, translocation studies in the water-submersed tissues of aquatic vascular plants were made. Since carbohydrates in the crown, rhizome, and root of aquatic plants appear to be equally available to the plant for new growth, in the emergent aquatic weed study the word "root" is used to include that part of the underground tissue below the line from which fibrous roots emerge.

Effective application of phytocides appears to require not only that fatty oxidized excretions forming the cuticle, when present, be penetrated but also that organic solvents be used in proper dilution. Studies were made to obtain information on the relative facility with

*Contributed jointly by the United States Department of Agriculture, Agricultural Research Service, Field Crops Research Branch, and the United States Department of Interior, Bureau of Reclamation, Engineering Laboratories, Denver, Colorado, for presentation before the Waterweed Control Section, National Weed Control Conference, Kansas City, Missouri, December 8–9, 1953.

which weedicides are absorbed and moved within the various plant parts under varied external conditions and of how plant physiological processes are altered, in bringing about a better weed killer performance.

The botanical nomenclature used corresponds to that found in Fernald's, Gray's Manual of Botany, 8th Edition (4).

CONTROL OF SUBMERSED WATERWEEDS (11)

Biological Control

Needle spike rush *(Eleocharis acicularis)* growing in direct sunlight is a water-submersed, low-growing, mat-forming plant. Histological studies have shown that shade-grown plants have about twice the diameter of those grown in direct sunlight. Also, it has been observed that plants grown in the shade grow to heights two to five times those grown in direct sunlight. These facts have an important bearing on the magnitude of resistance to the flow of irrigation water. This plant has the faculty of shade tolerance, but its resistance to water flow under such conditions is about six to nine times that of plants growing in direct sunlight.

Another plant, dwarf arrowhead *(Sagittaria subulata)*, growing in direct sunlight is also a water-submersed, low-growing, mat-forming plant. It has been observed, as in the case of needle spike rush, that in the absence of direct sunlight this plant grows to heights of two to five times those grown in the presence of direct sunlight. Over a 1-year period measurements of field migration have shown an average spread in all directions of 4 feet 8 inches for needle spike rush and 2 feet 3 inches for dwarf arrowhead. These observations were made in a relatively slow-flowing irrigation ditch.

There is laboratory evidence that either or both of these plants growing in association with the taller more obnoxious pondweed growth may, over a period of time, crowd out the pondweed growth. This suggests the desirability of planting one or both of these plants in irrigation ditches or lake bottoms for the purpose of holding shifting silt and preventing growth of the ranker growing pondweeds. After the needle spike rush or dwarf arrowhead crowds out the taller pondweed growth, succeeding growth becomes dwarfed in the presence of sunlight and causes much less resistance to the flow of water in the canal.

Heavy growths of the pond scum *Oedogonium* sp. have been observed to epiphytize plants of leafy pondweed *(Potamogeton foliosus)* to the extent the host plants were killed back to the submersed soil line a few weeks following the initial observable infestation.

Chemical Control

Beaker tests were performed in which concentrations varying from 5 to 800 ppm. of various solvents with 2 percent nonionic emulsifier added were placed in 30-minute contact with volumetrically measured excised portions of leafy pondweed. Increased herbicidal effectiveness with the chlorinated benzenes was noted in one series as indicated by an actual determination of regrowth 6 weeks following treatment. In this series, benzene was a more effective herbicide than

kerosene; and the monochloro-, dichloro-, and trichlorobenzenes were more effective herbicides than was benzene. Except at the higher concentrations, i.e., 400 and 800 ppm., polychlorobenzene was less effective as a herbicide. In another series, the methylated benzenes, i.e., toluene, xylene, and trimethylbenzene, were more effective herbicides than was benzene. Emulsified kerosene, benzene, dichlorobenzene, and trichlorobenzene were effective as algaecides in concentrations ranging from 5 to 800 ppm.

In general, the regrowth of leafy and sago pondweed *(P. pectinatus)* was approximately twice as rapid in undrained treated tanks as it was in those drained before treatment. It would seem from this work that in the field, aromatic solvent might be more effectively applied to irrigation systems by first gravity-draining the ditch and then spraying the flaccid water plants lying on the canal bottom with aromatic solvent. In those situations where it is impractical to drain a system or where movement along the bank is difficult, the present system of applying the chemical to the water for movement to the plants must suffice.

In many instances the field worker may elect to destroy the underground, as well as underwater, plant propagules. In the laboratory it has been determined that the following are approximate optimum quantities of 2,4–D per growing season simulating spray operations along gravity-drained canal bottoms, required to kill underground water plant propagules. Preceding the fruiting stage, two-thirds of each quantity listed should be applied with the first application and the remaining one-third should be applied later to any regrowth which may develop.

Plant	Lb. per acre of 2,4-D	Percent survival 6 weeks after application
Western waterweed *Elodea nuttallii*	5	0
American pondweed *Potamogeton nodosus*	12	5
Horsetail moss (Sago pondweed) *P. pectinatus*	15	5–10
Leafy pondweed *P. foliosus*	5	0– 5
Richardson's pondweed *P. richardsonii*	7	0–15
Horned pondweed *Zannichellia palustris*	7 or less	0
Water star grass *Heteranthera dubia*	7 or less	0

Apparently, 2,4–D killed the above-ground vegetative growth present at the time of tank treatments. The survival, present at the termination of the experiment, appeared to have come from latent bud propagules or seeds which had not started growth at the time of aerial herbicidal treatment.

Ten months following the placement of CMU, RADA (Rosin amine D acetate), 2,4–D acid, and sodium salt of 2,4–D as pellets and sodium borate as crystals on the soil bottom of tanks in which rooted aquatic plants were growing, observations were made as to the effectiveness of this technique in waterweed control. With the exception of dense waterweed *(Elodea densa)*, all submersed aquatic plants tested were killed with CMU concentrations of less than 10 ppm. The 2,4–D acid and sodium salt in concentrations between 20 and 25 ppm. cleared the tanks of the initial vascular plant growth

but permitted replacement by the pond scum, *Spirogyra*. Apparently concentrations of 100 ppm. or more of RADA are necessary to effectively eliminate the submersed aquatic aboveground growth. Depending upon the species treated, concentrations of sodium borate varying between 350 and 650 ppm. were necessary to eliminate aboveground submersed waterweed growth.

Waterweeds as Fertilizer

One possibility of defraying part of the cost of mechanical control of aquatic weeds centers around the use of harvested aquatic weeds as green manure to fertilize nearby farm lands. To investigate this possibility an exploratory test was made in which sago pondweed was harvested, processed to remove other plants and attached soil, oven-dried, and pulverized. Tomato and pepper plants, both with soil intact from 4-inch pots and with soil removed, were planted in a mixture containing 9 parts of Ottawa sand and 1 part of dried pulverized sago pondweed. After being watered as needed for 100 days, it was observed that the tomato and pepper plants growing in media containing pulverized pondweed had decidedly greener leaves than their counterparts growing in similar media but lacking the pulverized pondweed. Depending upon whether initial soil from the 4-inch pots was intact or whether it was removed, fresh weight of tomato plants growing in media containing pulverized pondweed was six and three times that of their counterparts growing in similar media but without the pulverized pondweed. Oven-dry weights were about four times as great for the plants growing in media containing pulverized pondweed as they were for those plants growing in the absence of the same. From this work it appears that pondweed plants might be used to advantage as fertilizer on adjacent farm properties to help defray the cost of weed removal from irrigation waterways.

Effect of Silt and Calcite Accumulation on Pondweed Leaf Surfaces

To study particle settling effect on aquatic plant growth, a prepared silt suspension was uniformly mixed in the surface water of tanks in which rooted leafy pondweed was growing. Within 2 weeks the plants began settling to the bottom of the tank and plant stems and leaves took on a brown appearance. This phenomenon was due to the mechanical settling of silt particles on the leaves. Six weeks after introduction of the silt there was definite evidence of new growth penetrating through the old. Eleven weeks after introduction of the silt, pondweed regrowth appeared to be complete. In this study calcite (formed by conversion of aragonite, the less stable form of $CaCO_3$) was secreted and accumulated by leaf cells on the aboveground plant surfaces. This self-deposition of calcite on the leaves, may, by obstructing light from the leaf, result in self-liquidation of the more mature plants. New plants apparently continue to develop from attached underground shoots until food reserves are exhausted during the new plant replacement process. It appears that the formation of calcite coatings on the leaves depends on an adequate supply of calcium being available to the plant.

CONTROL OF EMERGENT AQUATIC WEEDS (11)

Biological Control

For five consecutive growing seasons, a fenced area of pasture in which broad-leaved cattails *(Typha latifolia)* grew has intermittently been grazed rather intensively. Because a part of the pasture normally heavily infested with cattail growth had a fence line running through it, a contrast of cattail growth in the pasture area could be made between years in which heavy grazing occurred and the two consecutive growing seasons in which the area was protected from domestic grazing animals. In 1948 and 1949 when heavy grazing occurred, no cattails grew. In 1950 and 1951 when domestic animal grazing was prohibited, there was considerable cattail reinvasion, particularly in the second consecutive season in which grazing was prohibited in the previously heavily pastured area. The combination of eating the young cattail shoots together with mechanical injury to the plants by the hoofs of the grazing animals was sufficient to suppress growth. It is believed that the same control observed here could be accomplished on other farm properties where broad-leaved cattail infestation is interfering with normal agricultural practices.

In a migration study it was found that ripgut grass *(Carex aquatilis)* grows in water to a maximum depth of 12 inches. Broad-leaved cattail migrated about twice as fast as narrow-leaved cattail *(Typha angustifolia)* but produced only about half as many plants in a season's growth.

Chemical Control

Seasonal root reserve studies in the underground plant parts of untreated broad- and narrow-leaved cattail have been made in an attempt to correlate them with more readily observed aboveground seasonal growth phenomena. Having established the period, or periods, of low root reserve, it should thus be possible, by making herbicidal applications (contact or systemic) when root reserves are at a low ebb, to get maximum herbicidal effect with expenditure of minimum time, effort, and cost. A number of above-ground growth phenomena have been associated with below-ground food reserves. It will suffice here to say that water-inundated narrow-leaved cattail had its low point in root reserves when the plants had emerged to an average of 4 feet 11 inches above the water line. For noninundated narrow-leaved cattail, the low point in root reserves occurred when the plants had emerged 3 feet 11 inches above the ground line. For water-inundated broad-leaved cattail, the low point in root reserves occurred when the plants had emerged 4 feet 7 inches above the water line and for noninundated broad-leaved cattail, the low point in root reserves occurred when the plants had emerged 2 feet 6 inches above the ground line. Thus, the low point in seasonal carbohydrate root reserves varies not only with the species involved but with the growth habitat as well.

In a histological and chemical study to determine the effect of 2,4–D on the presence of starch grains in rhizomes of broad- and narrow-leaved cattail treated at rates varying from 1.4 to 108.1 pounds per acre, it was found that in both species of cattails: (a) the

starch grains were readily used up even when the lower concentrations of 2,4–D were applied; (b) in general, the percentage carbohydrate decreased as the higher quantity of 2,4–D per acre was applied; but decrease in carbohydrate was not in proportion to quantity of 2,4–D applied; (c) application of excessive amounts of 2,4–D did not deter utilization of carbohydrate reserves in the cattail roots; (d) the amount of carbohydrate reduction in the roots of untreated dormant plants as well as of growing plants receiving highest rates of 2,4–D was greater for the narrow-leaved species of cattail; (e) while carbohydrate content was comparatively high in the roots of narrow-leaved cattail, reduction of the carbohydrate content was more readily effected with a given application of 2,4–D, indicating this plant to be more susceptible to 2,4–D than the broad leaf species. This study emphasizes the fact that relatively small quantities of 2,4–D per acre used at the correct time of plant development and with an adequate cosolvent or wetting agent present are sufficient to have a pronounced effect on the reduction of starch grains and associated carbohydrates in cattail rhizomes upon which regrowth potential is dependent.

There are many instances where the field worker may wish to destroy the underground plant propagules of emergent aquatic plants. Table 1 gives the approximate optimum applications of 2,4–D which can effectively kill underground emergent water plant propagules as determined in the laboratory. Two-thirds of each quantity listed should be applied on first spray application and remaining one-third on any regrowth which might develop.

Table 1. Amounts of 2,4–D necessary for elimination or high percentage reduction of emergent aquatic weeds.

	Formulation of 2,4-D	Total pounds per acre	Percent survival 6 weeks after second application
True water cress *Nasturtium officinale*	Isopropyl ester	3.0	0
Water hyacinth *Eichornia crassipes*	Isopropyl ester	18.2	5
Parrot's feather *Myriophyllum brasiliense*	Isopropyl ester	3.0	0
Ripgut grass (Water sedge) *Carex aquatilis*	Acid	16.4	15
Oregon sugar grass (Awned sedge) *Carex atherodes*	Acid	34.0	5
Narrow-leaved cattail *Typha angustifolia*	Isopropyl ester	6– 8	0
Broad-leaved cattail *Typha latifolia*	Isopropyl ester	9–12	0

Ten months following the placement of CMU, RADA, 2,4–D acid, and sodium salt as pellets and sodium borate as crystals on the soil bottom of tanks in which rooted emergent aquatic plants were growing, observations were made as to the effectiveness of this technique in emergent waterweed control. All emergent aquatic plants tested, including water cress, parrot's feather *(Myriophyllum brasiliense),* and water hyacinth *(Eichornia crassipes)* were killed with CMU concentrations between 15 and 19 ppm. The 2-4–D acid at 224 ppm. cleared the tank of the initial vascular plant growth. Rosin amine D acetate in concentrations as low as 13 ppm. was effective in eliminating water cress growth. Sodium borate at a concentration of 736 ppm. eliminated 75 percent of the above-ground water cress growth. The 25 percent regrowth was stunted.

TOLERANCE OF CROPS TO HERBICIDES IN IRRIGATION WATER (12)

This investigation was made to determine relative tolerance of selected sensitive crop plants to irrigation waters containing varying concentrations of 2,4–D and other herbicides which, by accident or design, could fall into adjacent waters during spray operations of aquatic and ditchbank weeds and be carried to field crops. Aerial herbicidal applications were made on the flaccid aquatic plants which, in the absence of the usual supporting water, were lying on the soil in which they were rooted. The sprayed plants normally submerged were allowed to remain lying on the soil at the bottom of the tank for a period varying from ½ to 3 hours following spraying to allow the herbicides to penetrate the plant tissues. At the end of this period of time, the tanks with the sprayed plants were filled with tap water and drained immediately. This operation was repeated after which the tanks were filled a third time with tap water and flooded for 5 minutes. Quantities of these herbicide-contaminated wash waters were used to flood-irrigate cotton (Acala short staple), grape (Concord and Flame Tokay), and tomato (Chalk Early Jewell) plants. The soil used in these experiments consisted of one-third sand, one-third top soil, and one-third Michigan peat.

Tomato plants irrigated with tap water containing up to approximately 25 ppm. of 2,4–D were more vigorous than the untreated controls which, in each case, received the same amount of tap water containing no 2,4–D. At 25 ppm. and under conditions of this experiment, each application of 2,4–D amounted to 1.5 pounds per acre with 43 applications, making a total of 64.5 pounds of 2,4–D applied per acre.

In general, cotton plants irrigated with tap water containing up to approximately 11 ppm. of 2,4–D were more vigorous than the untreated controls which, in each case, received the same amount of tap water containing no 2,4–D. At 11 ppm. and under conditions of this experiment, each application of 2,4–D amounted to 0.8 pound per acre with 24 applications, making a total of 19.2 pounds of 2,4–D applied per acre.

Flame Tokay and Concord grape plants irrigated with tap water containing up to approximately 11 ppm. of 2,4–D showed sporadic injury to plants so treated. Injury occurred to some leaves on treated plants, whereas leaves of other treated plants entirely escaped 2,4–D injury. Because of the sporadic appearance of 2,4–D injured leaves on treated plants and untreated plants, it was believed that the injury was due to vaporization of the isopropyl ester contained in the irrigation water rather than to entry through the root system of the plants concerned.

In another set of experiments, tomatoes, cotton, and grapes were irrigated for 41 days with water containing Endothal at 100 and 200 ppm.; CMU at 7.4, 18.7, and 33.2 ppm.; RADA at 66.3 ppm.; 2,4–D sodium salt at 16.7 ppm.; and sodium borate at 458 ppm. Endothal at a concentration of 100 ppm. killed tomatoes after 15 days but appeared not to have injured cotton or grapes. Endothal at 200 ppm. killed tomatoes after 10 days and injured cotton but not grapes at

the end of 41 days. CMU at concentrations of 7.4 and 18.7 ppm. killed tomatoes after 10 days and showed some cotton injury after 41 days. Grapes showed no pronounced injury from the CMU irrigations. RADA at the concentration of 66.3 ppm. did not injure tomatoes or grapes but did injure cotton after 41 days. The sodium salt of 2,4–D in the concentration of 16.7 ppm. did not injure tomatoes and grapes but caused some injury to cotton after 41 days. Sodium borate at 458 ppm. killed tomatoes at the end of 20 days but did not injure cotton or grapes after 41 days.

The fungus *Phoma* sp. has been found to concentrate 2,4–D–51 and the algae *Cladophora* sp. and *Spirogyra* sp. have been found to concentrate 2,4–D–$1C^{14}$. It seems likely that other members of Thallophyta, e.g., soil actinomyces and bacteria, play an important role in rendering 2,4–D in soil innocuous to crop plants through assimilating the compound into the various plant bodies.

Two goldfish suffered no apparent injury from exposure to CMU at a concentration of 14.9 ppm. for 35 days. One of the goldfish died from 2 days' exposure to a CMU concentration of 59.5 ppm. The second goldfish died after a 7-day exposure to the same concentration. Apparently CMU will kill waterweeds at concentrations safe for goldfish, back swimmers (family notonectidae), and perhaps other forms of aquatic animal life.

It is believed that the dilution of 2,4–D in irrigation waters under field conditions would be even greater than those obtained in the laboratory. Thus, if the laboratory wash waters were safe to use on such farm crops as cotton, tomatoes and grapes, contaminated water should also be safe to use under field conditions since crops would not often be irrigated with contaminated water.

From this work it appears likely that it should be safe to crease irrigate field plants of these crops with waters passing over weed areas previously treated with any of the herbicides discussed in this paper, provided the initial 5 minutes of wash waters traversing these herbicidal field-treated areas are wasted, i.e., not turned into a field for immediate irrigation.

STUDIES OF HERBICIDAL ACTION ON AQUATIC WEEDS USING RADIOACTIVE 2,4–D–$1C^{14}$ (13)

Radioactive 2,4–D–$1C^{14}$ was mixed with eight different additive combinations in an attempt to obtain information on which combination would most readily facilitate movement of 2,4–D through an emergent aquatic plant, as represented by broad-leaved cattail, and a submersed aquatic plant, as represented by American pondweed *(Potamogeton nodosus)*. The herbicides were placed about 6 inches from the tip of the cattail leaf and at the base of the American pondweed leaf. Eighty specimens of each species were treated, i.e., ten with each formulation. Half of the treated specimens were harvested after 2 weeks' exposure time; the other half were harvested after 6 weeks' exposure time. Autoradiographs were made of whole specimens of the dried pondweed, whereas autoradiographs were made on treated and untreated cattail leaf series cut into 11-inch segments. Carbowax was used as cosolvent, and water served as car-

rier for the first six formulations. Tributyl phosphate served as co-solvent for the last two formulations with kerosene being the carrier in Formulation No. 7 and xylene in No. 8.

In both American pondweed, whose emergent leaves float on the water surface, and broad-leaved cattail, the radioactive 2,4–D readily passed the water line and also accumulated in the roots. The C^{14} atom was translocated generally in a downward direction to the rhizome-root system and thence to other untreated parts attached to the treated portions.

Movement of radioactive 2,4–D–$1C^{14}$ through the rhizome and passage into untreated leaves of the same plant was accomplished most readily by the combination of 2,4–D with carbowax, water, Vatsol OTB, or Linck wetting agent. When tributyl phosphate and kerosene or xylene were used with 2,4–D, the majority of the 2,4–D appeared to be retained in the upper half of the treated leaf. However, even in these cases, diffusion of some radioactive material throughout the treated leaves and past the rhizome to untreated leaves was evident.

Thallophytes, including a fungus and two algae, were active in assimilating radioactive 2,4–D with the various chemical additives present.

BIOLOGICAL CORROSION OF CONCRETE (14)

In November 1948, sections of the Cherry Creek (Denver, Colorado) concrete retaining wall were observed to be in an aggravated friable condition with algae (green and blue-green), lichens (crustose and foliose), and mosses growing readily thereon.

Since sulfur is present in varying amounts in all concrete made with portland cement and since the lower forms of plant life are known to be concentrators of sulfur, it was decided to make a comparative study of the relative effect of lower plants on concrete with high SO_3 content as compared to concrete with low SO_3 content. A uniform aggregate was mixed with two portland cements containing approximately 1 percent SO_3 and with two other portland cements containing approximately 4 per cent SO_3. These mixtures were fabricated into four 11- by 15- by 2-inch mortar slabs. Cubes of 2- by 2- by 2-inch dimensions were made of a portland cement with about a 4 percent SO_3 content. Cylinders of 3- by 6-inch dimensions were made with a cement containing an intermediate SO_3 content. After fabrication and 28 days in a 70° F., 100 percent relative humidity room, all of the mortar specimens were inoculated with plant cultures obtained from the Cherry Creek retaining wall. One set of 3- by 6-inch cylinders were immersed in tap water containing the cultures. Other specimens were placed in a 100 per cent relative humidity room. Half of each of the four slabs was covered with Ottawa sand to prevent or deter plant growth. The other half of each of the slabs was planted with the cultures obtained from the Cherry Creek retaining wall.

After approximately 5 years of exposure of the concrete to the plants, the plants were removed with a wire brush, the concrete specimens placed in the freezing and thawing unit for 50 cycles of freezing and thawing to accentuate the plant effects and facilitate observa-

tions made on the specimens. In those instances where the culture plants came in contact with mortar having 0.6 percent or more SO_3, pitting of the mortar surface was very pronounced. Pitting of the surface was much less when SO_3 percent was about 0.2%. Apparently the gelatin present in the growing plants together with the organic acids produced by them, e.g., carbonic, oxalic, and silicic, was adequate to corrode the surfaces of the mortar when the SO_3 content was high.

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Some Chemical and Physical Properties of Weed Killers

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The following table of chemical and physical properties of some herbicides was compiled as an aid to agricultural research workers.

It is realized that not only is the list of chemicals incomplete but many of the properties are lacking. Any such omissions were not deliberate but were due to unavailability to the authors of such information. It is earnestly hoped that there will be future contributions to this compilation.

We wish to express our thanks to the many people and organizations that supplied information for this list.

Explanation of Table:

The chemicals are arranged alphabetically according to Chemical Abstracts' nomenclature.

Density is given at 20° C referred to water at 4° C. Specific gravities are at the indicated temperatures. The melting point is of the commercially used material unless otherwise specified. $-H_2O$ indicates loss of water.

The pH value is for 5% solutions in water or alcohol unless otherwise indicated.

It is thought best to mention here the authors' meaning of the terms "non-volatile", "low volatile", and "volatile". It is realized that these terms are confusing, but it was thought that to include some indication of the vapor pressure would be of benefit. The above designations refer to that amount of volatility that is required to adversely affect common herbaceous crops and weeds. Thus, by "non-volatile" is meant those compounds whose volatile products, if present, do not adversely affect plants under temperatures encountered where plants are grown. By "low volatile" is meant those compounds whose volatile products do not affect plants under normal temperatures, but under extreme temperatures may show evidences of volatility by affecting nearby susceptible plants. By "volatile" is meant those compounds that can be expected to adversely affect nearby plants under normal temperatures. The authors have given one of the above definitions to a compound only where this definition of said compound has been available in the literature.

Abbreviations:

alc. = alcohol
alk. = alkali
cry. = crystallizes
decomp. = decompose (s)
deliq. = deliquescent
effl. = efflorescent
ev. = evolves
expl. = explodes
extr. = extreme (ly)
flash p. = flash point
flam. = flammable
hyd. = hydrolyzed
hyg. = hygroscopic
insol. = insoluble
misc. = miscible
mm = millimeter (s)
m.p. = melting point
org. = organic
petr. = petroleum
ppm = parts per million
ppt. = precipitate
sequ. = sequestering
sl. = slight (ly)
sol. = soluble
solv. = solvent (s)
sp. gr. = specific gravity
subl. = sublimes
tech. = technical
temp. = temperature
volt. = volatizes, volatile
> = above
< = below

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Name	Empirical formula	Sp. gr. or density °C	M.P. °C	Vapor pressure mm Hg @ °C	pH	Solubility		Remarks
						Water		
Acetic acid, chloro-, sodium salt	$C_2H_2ClNaO_2$		decomp. 200	low volt.	5–6	very sol.		sl. hyg., needs no sequ.
Acetic acid, 4-chloro-o-tolyloxy-, (MCP)	$C_9H_9ClO_3$	1.35 20/15.5	pure 118–119 tech 99–107	low volt.	2.8	insol.	org. solv.	non-hyg.
Acetic acid, 4-chloro-o-tolyloxy-, mixed amine salt	$C_9H_9ClO_3$. C_3H_9NO-$C_4H_{11}NO_3$	1.26 20/15.5		low volt.	7.2	sol.		needs sequ.
Acetic acid, 4-chloro-o-tolyloxy-, sodium salt	$C_9H_8ClNaO_3$		223–225	non-volatile	9.0	27%	34% methanol 0.1% benzene	non-hyg., needs sequ.
Acetic acid, 2,4-dichlorophenoxy-,	$C_8H_6Cl_2O_3$	1.565 30	139–139.5	0.4 @ 160	3.0	550 ppm	sl. in alc.	non-hyg.
Acetic acid, 2,4-dichlorophenoxy-, 2-aminoethanol salt	$C_{10}H_{13}Cl_2NO_4$		145–147	low volt.	7.6	sol.		needs sequ.
Acetic acid, 2,4-dichlorophenoxy-, 2,3-butanediol diester	$C_{20}H_{18}Cl_4O_6$			low volt.			petr. solv.	
Acetic acid, 2,4-dichlorophenoxy-, butoxyethoxypropyl ester	$C_{17}H_{24}Cl_2O_5$			low volt.			org. solv.	
Acetic acid, 2,4-dichlorophenoxy-, butoxyethyl ester	$C_{14}H_{18}Cl_2O_4$	1.232 22		1.7×10^{-3} @ 25 1 @ 156–160			org. solv.	
Acetic acid, 2,4-dichlorophenoxy-, butyl ester	$C_{12}H_{14}Cl_2O_3$	1.25 15.5/15.5	9	4.5×10^{-3} @ 25	4.8	insol.	alcohol and petr. oils	
Acetic acid, 2,4-dichlorophenoxy-, capryl ester	$C_{18}H_{26}Cl_2O_3$			low volt.		insol.	org. solv.	
Acetic acid, 2,4-dichlorophenoxy-, diethylamine salt	$C_{12}H_{17}Cl_2NO_3$		105–108	low volt.	7.1	sol.		needs sequ.
Acetic acid, 2,4-dichlorophenoxy-, dimethylamine salt	$C_{10}H_{13}Cl_2NO_3$		85–87	low volt.	7.5	sol.		needs sequ.

Name	Empirical formula	Sp. gr. or density °C	M.P. °C	Vapor pressure mm Hg @ °C	pH	Solubility		Remarks
						Water		
Acetic acid, 2,4-dichlorophenoxy-, dipropylene glycol iso-octyl ester	$C_{22}H_{32}Cl_2O_5$			low volt.			petr. oils	
Acetic acid, 2,4-dichlorophenoxy-, ethoxyethoxypropyl ester	$C_{16}H_{22}Cl_2O_5$			low volt.			petr. oils	
Acetic acid, 2,4-dichlorophenoxy-, ethyl ester	$C_{10}H_{10}Cl_2O_3$	1.325 23	16	2 @ 143–145		insol.	alcohol and petr. oils	
Acetic acid, 2,4-dichlorophenoxy-, ethylamine salt	$C_{10}H_{13}Cl_2NO_3$		129–131	low volt.	7.5	sol.		needs sequ.
Acetic acid, 2,4-dichlorophenoxy-, 2,2′ – iminodiethanol salt	$C_{12}H_{17}Cl_2NO_5$	1.35 20/15.5	76–78	low volt.	7.9	sol.		needs sequ.
Acetic acid, 2,4-dichlorophenoxy-, isopropylamine salt	$C_{11}H_{13}Cl_2NO_3$			low volt.	7.2	sol.		needs sequ.
Acetic acid, 2,4-dichlorophenoxy-, isopropyl ester	$C_{11}H_{12}Cl_2O_3$	1.24–1.29 20	23–27	10.3×10^{-3} @ 25 1 @ 130	5.4	insol.	alcohol and petr. oils	cry. in 2 forms
Acetic acid, 2,4-dichlorophenoxy-, methylamine salt	$C_9H_{11}Cl_2NO_3$		157–159	low volt.	7.0	sol.		needs sequ.
Acetic acid, 2, 4-dichlorophenoxy-, mixed amine salt	$C_8H_6Cl_2O_3$. C_3H_9NO–$C_4H_{11}NO_2$	1.24 20/15.5		low volt.	7.7	sol.		needs sequ.
Acetic acid, 2,4-dichlorophenoxy-, 2, 2′,2″-nitrilotriethanol salt	$C_{14}H_{21}Cl_2NO_6$	1.33 20/20	94–95	low volt.	7.5	82% @ 32°C		needs sequ.
Acetic acid, 2,4-dichlorophenoxy-, polyethylene glycol ester	$C_8H_8Cl_2O_3$. $(C_2H_4O)_xH$		35	low volt.	2.7	sl. sol.	org. solv.	
Acetic acid, 2,4-dichlorophenoxy-, (polypropylene glycol butyl ether) ester	$C_8H_8Cl_2O_3$. (C_3H_6O to $C_9H_{18}O_3$)C_4H_9O	1.20 15.5/15.5	<–32	low volt	4.0		alcohol and org. solv.	

Name	Empirical formula	Sp. gr. or density °C	M.P. °C	Vapor pressure mm Hg @ °C	pH	Solubility		Remarks
						Water		
Acetic acid, 2,4-dichlorophenoxy-, sodium salt	$C_8H_6Cl_2NaO_4.H_2O$		$-H_2O$ 105 213–215 decomp. 215	non-volatile	9.0	4.5%		needs sequ., sl. hyg.
Acetic acid, 2,4-dichlorophenoxy-, tetrahydrofurfuryl ester	$C_{13}H_{14}Cl_2O_4$			0.1×10^{-3} @ 55			org. solv.	
Acetic acid, 2,4-dichlorophenoxy-, triethylamine salt	$C_{14}H_{21}Cl_2NO_3$		1.21 20/20	low volt.	7.0	sol.		needs sequ.
Acetic acid, 3,4-dichlorophenoxy-, butoxyethyl ester	$C_{14}H_{18}Cl_2O_4$			low volt.			org. solv.	
Acetic acid, 3, 4-dichlorophenoxy-, 2, 2′, 2″-nitrilotriethanol salt	$C_{14}H_{21}Cl_2NO_6$			low volt.	7.5	sol.		needs sequ.
Acetic acid, 2-methoxy-2-phenyl-,	$C_9H_{10}O_3$						org. solv.	
Acetic acid, trichloro-,	$C_2HCl_3O_2$	1.62 25/4	56.9	760 @ 196–7 1 @ 51.0	0.5	54%	alcohol	hyg., decomp. at elevated temp., deliq.
Acetic acid, trichloro-, sodium salt	$C_2Cl_3NaO_2$		decomp.	non-volatile	5.5–6	sol.	alc., sl. in org. solv.	needs no sequ., hyg.
Acetic acid, 2,4,5-trichlorophenoxy-,	$C_8H_5Cl_3O_3$	1.80 20/20	154–155	low volt.	3.0	200 ppm	sl. petr. solv.	needs sequ.
Acetic acid, 2,4,5-trichlorophenoxy-, 2-aminoethanol salt	$C_{10}H_{12}Cl_3NO_4$		179–181	low volt.	7.5	sol.		needs sequ.
Acetic acid, 2,4,5-trichlorophenoxy-, 2,3-butanediol diester	$C_{20}H_{19}Cl_6O_6$			low volt			petr. oils	
Acetic acid, 2,4,5-trichlorophenoxy-, butoxyethoxypropyl ester	$C_{17}H_{23}Cl_3O_5$	1.25	−5 to 0	<0.01 @ 20 low volt.			org. solv.	

Name	Empirical formula	Sp. gr. or density °C	M.P. °C	Vapor pressure mm Hg @ °C	pH	Solubility		Remarks
						Water		
Acetic acid, 2,4,5-trichlorophenoxy-, 2-butoxyethyl ester	$C_{14}H_{17}Cl_3O_4$	1.30	26	low volt. 1 @ 163–166		insol.	org. solv.	
Acetic acid, 2,4,5-trichlorophenoxy-, butyl ester	$C_{12}H_{13}Cl_3O_3$	1.32 20/15.5	30	2.0×10^{-3} @ 25	3.5	insol.	org. solv.	
Acetic acid, 2,4,5-trichlorophenoxy-, capryl ester	$C_{16}H_{21}Cl_3O_3$			low volt.		insol.	org. solv.	
Acetic acid, 2,4,5-trichlorophenoxy-, dipropylene glycol iso-octyl ester	$C_{22}H_{31}Cl_3O_6$			low volt.			petr. oils	
Acetic acid, 2,4,5-trichlorophenoxy-, ethoxyethoxypropyl ester	$C_{15}H_{19}Cl_3O_5$			low volt			petr. oils	
Acetic acid, 2,4,5-trichlorophenoxy-, 2, 2′-iminodiethanol salt	$C_{12}H_{16}Cl_3NO_5$		157–159	low volt.	7.5	sol.		needs sequ.
Acetic acid, 2,4,5-trichlorophenoxy-, isopropyl ester	$C_{11}H_{11}Cl_3O_3$	1.33 20/15.5	42–46	volatile 0.5 @ 157	3.3	insol.	org. solv.	
Acetic acid, 2,4,5-trichlorophenoxy-, 2, 2′, 2″–nitrilotriethanol salt	$C_{14}H_{20}Cl_3NO_6$	1.34 20/20	116–117	low volt.	7.5	sol.		sl. hyg., needs sequ.
Acetic acid, 2,4,5-trichlorophenoxy-, polyethylene glycol ester	$C_8H_5Cl_3O_3$. $(C_2H_4O)_xH$	1.65 20/15.5	70–73	low volt.	2.5		org. solv.	
Acetic acid, 2,4,5-trichlorophenoxy-, (polypropylene glycol butyl ether) ester	$C_8H_5Cl_3O_3$. (C_3H_6O to $C_9H_{18}O_3$)C_4H_9O	1.25 20/15.5	<–32	low volt. 2.5 @ 200	3.4		org. solv.	
Acetic acid, 2,4,5-trichlorophenoxy-, tetrahydrofurfuryl ester	$C_{13}H_{13}Cl_3O_4$		>30	low volt.			org. solv.	

Name	Empirical formula	Sp. gr. or density °C	M.P. °C	Vapor pressure mm Hg @ °C	pH	Solubility		Remarks
						Water		
Acetic acid, 2,4,5-trichlorophenoxy-, triethylamine salt	$C_{14}H_{20}Cl_3NO_3$		104–106	low volt.	7.5	sol.	alcohol	non-hyg., needs sequ.
Acrylic acid, a-cyano-b-(2,4-dichlorophenyl)-,	$C_{10}H_5Cl_2NO_2$		197.5–198.3					
Acrylic acid, a-cyano-b-(2,4-dichlorophenyl)-, 2,2′-iminodiethanol salt	$C_{14}H_{16}Cl_2NO_4$		137.9–138.9			sol.		
Allyl alcohol	C_3H_6O	0.852–0.855 20/4	–129	17.3 @ 20 760 @ 95–98	4.5	misc.	alcohol	flash p. T.O.C. 85°C
Ammonium chlorate	NH_4ClO_3		expl. 102			sol.	sl. alc.	needs no sequ., expl. by percussion
Ammonium sulfamate	$H_6N_2O_3S$		tech 125 pure 132 decomp. 160	low volt.	5.2	60%	alc. and ketones	non-flam., hyg., not compatible aldehydes
Ammonium thiocyanate	CH_4N_2S	1.31	149 decomp. 170		4.5–5.5	63%	35% methanol	hyg., deliq., needs no sequ., ev. HCN with acid
Arsenic pentaoxide	As_2O_5	4.09	decomp. 315		2.0	59%	alc. and alk.	non-hyg., deliq.
Arsenic trichloride	$AsCl_3$	2.16	–18	10 @ 23.5 760 @ 130.2		decomp.	acid and alcohol	
Arsenic trioxide	As_2O_3	3.75–3.86	monoclinic 313–315 octahedral 275	60 @ 310	3.7	2%	sl. alc.	subl. 193°, non-hyg., non-flam., unstable in acid and alk.
Benzene, 1,2,4(1,2,3)-trichloro-,	$C_6H_3Cl_3$	1.46 25/25	7.5	25 @ 100 760 @ 214.8 volt. with steam	6.5	insol.	org. solv.	flash p. 100°C
Benzoic acid, 2,3,6-trichloro-,	$C_7H_3Cl_3O_2$		87–99			sl. sol.	alcohol	subl.

Name	Empirical formula	Sp. gr. or density °C	M.P. °C	Vapor pressure mm Hg @ °C	pH	Solubility		Remarks
						Water		
Benzoic acid, 2,3,6-trichloro-, sodium salt	$C_7H_2Cl_3NaO_2$					sol.		
Calcium chlorate	$Ca(ClO_3)_2.2H_2O$	2.71	−1 H_2O 100			64%	alcohol	deliq., hyg.
Calcium cyanamide	$CCaN_2$	2.3	subl. 1300	760 @ 1199	8.5	insol.		decomp. ev. NH_3, hyd. in water
Calcium cyanate	$Ca(OCN)_2$							non-flam.
Calcium thiocyanate	$Ca(CNS)_2.3H_2O$					sol.	alcohol	deliq., ev. HCN with acid, hyg.
Carbanilic acid, isopropyl ester	$C_{10}H_{13}NO_2$	1.09 20/20	pure 90 tech 85–87.5	volatile	6.5–7.5	250 ppm	halo-hydro-carbon	non-hyg.
Carbanilic acid, m-chloro-, isopropyl ester	$C_{10}H_{12}ClNO_2$	1.27 20/20	36–41.4	volatile 0.1 @ 138–139.5	7.5	108 ppm	org. solv.	non-hyg., flash p. 110°C
Carbon disulfide	CS_2	1.26 25/25	−109 to −111	290 @ 20 760 @ 46.3	7.0	2000 ppm	org. solv.	extr. flam., flash p. −25 to −30
Chloropicrin	CCl_3NO_2	1.66 20/20	−64	20 @ 20 760 @ 112		2000 ppm	alcohol	non-flam., non-corrosive
Colemanite	$2CaO.3B_2O_3.5H_2O$	2.43		non-volatile		1500 ppm		30–35% B_2O_3
Copper sulfate pentahydrate	$CuSO_4.5H_2O$	2.28	$-2H_2O$ 45, $-4H_2O$ 110, $-5H_2O$ 150, 200, decomp. 650	non-volatile	4.0	24%	methanol	effl., needs no sequ.
o-Cresol, 4,6-dinitro-,	$C_7H_6N_2O_5$	1.49	86–86.9	105×10^{-6} @ 25 760 @ 312 volt. in steam	3.2	250 ppm	3.5% in alc.	non-hyg., decomp. with heat
o-Cresol, 4,6-dinitro-, sodium salt	$C_7H_5N_2NaO_5$					sol.		dry product flam., non-corsive
o-Cresol, 4,6-dinitro-, triethylamine salt	$C_{13}H_{21}N_3O_5$	1.11 20/20	42–44.5		8–8.		mix alc. and water	needs sequ., non-hyg.
Cyanamide	CH_2N_2	1.07 48/4	44 decomp. 140	760 @ 260		80%	alc. and benzene	deliq., flash p. 141°C

Name	Empirical formula	Sp. gr. or density °C	M.P. °C	Vapor pressure mm Hg @ °C	pH	Solubility		Remarks
						Water		
Ethane, 1,1,2,2-tetrachloro-,	$C_2H_2Cl_4$	1.60 25/25	−36 to −43.8	5 @ 20.7 760 @ 146	6.0	insol.	alc. and org. solv.	
Ethanol, 2-(2, 4-dichlorophenoxy)-,	$C_8H_8Cl_2O_2$		49.5–40	100 @ 225, 10 @ 164	6.0	insol.	petr. solv. and alc.	non-hyg., needs no sequ.
Ethanol, 2-(2,4-dichlorophenoxy)-, sulfate sodium salt	$C_8H_7Cl_2NaO_6S$		170	non-volatile	9.5	25%		needs sequ., non-hyg.
Ethanol, 2-(2,4,5-trichlorophenoxy)-,	$C_8H_7Cl_3O_2$		60.5–63.5	760 @ 325, 10 @ 182.1	7.0	insol.	petr. solv. and alc.	non-hyg., needs no sequ.
Ethanol, 2-(2,4,5-trichlorophenoxy)-, sulfate sodium salt	$C_8H_6Cl_3NaO_6S$		258–260 with decomp.	non-volatile	8.2	sol.		needs sequ., non-hyg.
Formaldehyde	CH_2O	0.815 −20/4	−92	760 @ −19.5	3.8	sol.	ether, alc.	polymerizes at room temp., flash p. 55°C., flam.
10-Hendecenoic acid	$C_{11}H_{20}O_2$	0.9075 25/4	24.5 decomp. 295	760 @ 275 1 @ 114		insol.	alcohol	
Kainite	$MgSO_4.KCl.3H_2O$	2.007–2.188 20/20				sol.		
Magnesium chlorate	$Mg(ClO_3)_2.6H_2O$	1.80 25/25	35, decomp. 120	non-volatile	6.2–6.7	57%	alcohol	deliq., needs no sequ.
Methyl bromide	CH_3Br	1.73 0/4	−93	760 @ 4.5		900 ppm	org. solv.	non-flam.
7-Oxabicyclo (2.2.1) heptane-2,3-dicarboxylic acid, disodium salt (3,6-endoxohexahydrophthalate)	$C_8H_8Na_2O_5$		263–266		5.7	sol.	alcohol, insol. org. solv.	sl. hyg., needs no sequ., corrosive
Phenol, 2-sec-amyl-4,6-dinitro-,	$C_{11}H_{14}N_2O_5$	1.25 20/15.5		volt. steam	2.7		petr. solv. and alc.	non-hyg., decomp. with heat
Phenol, 2-sec-butyl-4,6-dinitro-,	$C_{10}H_{12}N_2O_5$	1.29 20/15.5	pure 37.9–39.3 tech 28	volt. in steam	3.2	insol.	petr. solv.	non-hyg., decomp. with heat

Name	Empirical formula	Sp. gr. or density °C	M.P. °C	Vapor pressure mm Hg @ °C	pH	Solubility		Remarks
						Water		
Phenol, 2-sec-butyl-4,6-dinitro-, alkanolamine salt	$C_{10}H_{12}N_2O_5$. C_2H_7NO-$C_6H_{15}NO_3$	1.20 20/20	71–73		7.6	sol.		needs sequ.
Phenol, 2-sec-butyl-4,6-dinitro-, ammonium salt	$C_{10}H_{12}N_2O_5.NH_4$		158–159.5		7.0	sol.	20% ethanol	needs no sequ., non-flam., decomp. with heat
Phenol, pentachloro-,	C_6HCl_5O	1.95 25/25	tech 187–189 pure 191 decomp. 310	0.12 @ 100 760 @ 293 volt. in steam	3.7	1.6 ppm	oxygenated solv., sl. solv. petr. solv.	non-hyg., non-flam., non-corrosive
Phenol, pentachloro-, sodium salt	C_6Cl_5NaO	1.99 25/25	>320	non-volatile	9–11.5	33%	alc., insol. org. solv.	non-flam., non-hyg., needs sequ.
Phenyl mercuric acetate	$C_8H_8HgO_2$		149–153	volatile		4700 ppm	alc. and ketones	ppt. with chloride
Phenyl mercuric acetate, 2, 2′, 2″-nitrilotriethanol salt	$C_{14}H_{21}HgNO_5$		126			sol.	alc., sl. sol. petr. oils	needs sequ., decomp. by heat, ppt. by halides
Phthalamic acid, N-1-naphthyl-,	$C_{18}H_{13}NO_3$	1.35–1.45 20/20	175–180			200 ppm	sl. sol. org. solv.	hyd. by strong acids and alk.
Potassium chlorate	$KClO_3$	2.32	368.4 decomp. 400	non-volatile	7.5	7%	8300 ppm alcohol	sl. hyg., needs no sequ.
Potassium cyanate	KOCN	2.06 20/20	315 decomp. 700–900	non-volatile	9.2	39%	insol. org. solv.	non-flam., slowly hyd. in water, expl. with chlorates, hyg.
Potassium thiocyanate	KSCN	1.886	173.2 decomp. 500	760 @ 500	5.5	64%	alcohol	deliq., ev. HCN with acid.
Propionic acid, 2,2-dichloro-, sodium salt	$C_3H_3Cl_2NaO_2$		193–197	non-volatile	5.5–6	sol.	alc., sl. solv. org. solv.	needs no sequ., hyg., decomp. elevated temp.

Name	Empirical formula	Sp. gr. or density °C	M.P. °C	Vapor pressure mm Hg @ °C	pH	Solubility		Remarks
						Water		
Propionic acid, 2-(2,4,5-trichlorophenoxy)-,	$C_9H_7Cl_3O_3$		179–181	low volt.	3.0	sol. 140 ppm	sl. sol. petr. oils and alc.	
Propionic acid, 2-(2,4,5-trichlorophenoxy)-, butoxyethyl ester	$C_{15}H_{19}Cl_3O_4$			low volt.			petr. oils	
Propionic acid, 2-(2,4,5-trichlorophenoxy)-, 2, 2′, 2″-nitrilotriethanol salt	$C_{15}H_{22}Cl_3NO_6$		120.5–123	low volt.		sol.		needs sequ.
Propionic acid, 2-(2,4,5-trichlorophenoxy)-, (polypropylene glycol butyl ether) ester	$C_9H_5Cl_3O_3$. (C_3H_6O to $C_9H_{18}O_3$)C_4H_9O	1.21 20/15.5		low volt.	3.5		org. solv.	
3,6-Pyridazinedione, 1,2-dihydro-, (maleic hydrazide)	$C_4H_4N_2O_2$	1.60 @ 25	pure 296–298 tech 290 decomp. 260	non-volatile	5.0	0.4%	alcohol	non-flam.
3,6-Pyridazinedione, 1,2-dihydro-, 2, 2′-iminodiethanol salt	$C_8H_{11}N_3O_4$	1.30 20/20		non-volatile	8.0	sol.		needs no sequ.
3,6-Pyridazinedione, 1,2-dihydro-, sodium salt	$C_4H_3N_2NaO_2$			non-volatile		sol.		hyg.
Rosin Amine D Acetate	$C_{22}H_{33}NO_2$	1.07 @ 25	decomp. 90	low volt.	5.9	sol.	alcohol	needs no sequ.
Sodium arsenate	$Na_3AsO_4.12H_2O$	1.76–1.80 20/20	86.3		8.7	21%	alcohol	sl. hyg.
Sodium arsenate (meta)	$NaAsO_2$	2.30 20/20						effl.
Sodium arsenite	$NaAsO_2$ or Na_2HAsO_3	1.87	>350		9.7	sol. sol.	sl. sol. alcohol	sl. hyg., needs no sequ., non-flam.
Sodium chlorate	$NaClO_3$	2.49 15/15	248 decomp. 300	non-volatile	6.7	50%	alcohol	non-hyg. fire hazard, needs no sequ.

Name	Empirical formula	Sp. gr. or density °C	M.P. °C	Vapor pressure mm Hg @ °C	pH	Solubility		Remarks
						Water		
Sodium cyanamide	$CHNaN_2$				11.0	sol.		very aklaline
Sodium fluoride	NaF	2.79	980–997	1 @ 1077 760 @ 1700	6.8	4%	sl. sol. alcohol	non-hyg., needs sequ.
Sodium metaborate	$NaBO_2.4H_2O$	1.73 23	53.5, $-H_2O$ at 120	non-volatile 760 @ 1230 +	11.1	73.5%	Ca salt sl. sol.	
Sodium pentaborate	$Na_2B_{10}O_{16}.10H_2O$	1.71 23	755	non-volatile	8.0	15%		
Sodium selenite	Na_2SeO_3	3.10 20/20				45%	insol. alc.	
Sodium tetraborate	$Na_2B_4O_7.10H_2O$	1.73	62, $-5H_2O$ 100, $-9H_2O$ 150, $-10H_2O$ 320	non-volatile 760 @ 1848	9.2–9.5	5.1%	insol. alc.	deliq., effl. in warm dry air, non-flam., Ca salt sl. sol.
Sodium thiocyanate	NaCNS		287		7.0	58%	alc. and acetone	ev. HCN with acid, deliq.
Sulfuric acid	H_2SO_4	pure 1.834 18/4 tech 1.68–1.71 18/4	decomp. 340, anhydrous +10, 65% @ −64	1 @ 145.8 760 @ 210-330	0.01 N 2.1	very sol.		hyg., needs no sequ., reacts violently with water
1,2,4-Triazole, 3-amino-,	$C_2H_4N_4$		155.1–156.0		0.1M 6–6.3	19.3% @ 23		
Ulexite	$NaCaB_5O_9.8H_2O$	1.65		non-volatile		slight		
Urea, 1,3-bis(2,2,2-trichloro-1-hydroxyethyl)-, (dichloral urea)	$C_5H_6Cl_6N_2O_3$		191 with decomp.			slight	sl. sol. org. solv., good in cyclic-ketones	
Urea, 3-(p-chlorophenyl)-1, 1-dimethyl-,	$C_9H_{11}ClN_2O$	1.27 20/20	167–171	5×10^{-7} @ 25 9×10^{-8} @ 27	6.5	230 ppm	sl. sol. org. solv.	non-flam., non-hyg., non-corrosive
Urea, 3-(3,4-dichlorophenyl)-1, 1-dimethyl-,	$C_9H_{10}Cl_2N_2O$		153–155	2×10^{-7} @ 30		insol.	insol. org. solv., sol. in acetone	non-flam., non-hyg., non-corrosive
Urea, 1,1-dimethyl-3-phenyl-,	$C_9H_{12}N_2O$	1.08 20/20	127–131.5	1.6×10^{-4} @ 60	8.0	0.29%	alc., sl. solv. org. solv.	non-hyg.

Name	Empirical formula	Sp. gr. or density °C	M.P. °C	Vapor pressure mm Hg @ °C	pH	Solubility		Remarks
						Water		
Xanthic acid, ethyl-, sodium salt	$C_3H_5NaOS_2$		decomp. 200		10.4	sol.	alcohol	non-hyg., needs no sequ.
Xanthic acid, isopropyl-, sodium salt	$C_4H_7NaOS_2$		123–124		11.0	12.1% @ O°C 38% @ 30°C		non-hyg.
Oils, weed	Special	gravity 27–30° API		IBP 400°F E.P. 700°F				Aromatics >50%
Oils, weed	Diesel oil (average values)	gravity 32.6° API		distillation range: 10%—453° F 90%—623° F				flash point (PMCC) 176°F viscosity (Saybolt Univ. @ 100°F) 39.6 sec. unsulfonated residue 79.6%
Oils, weed	Naphtha (aquatic weeds)			distillation range: ASTM D86 278° F–420°F				flash point>80°F aromatics ASTM D875>85%

Effect of Sodium Trichloroacetate on the Intake of Nutrients by Wheat Plants Grown in Oshtemo Sand at Low and High Fertility Levels

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Introduction

When wheat seedlings are injured by trichloroacetate (TCA) the leaves turn yellow in much the same manner as do those on plants growing in media where the nutrients are unbalanced. Accordingly, there is the possibility that TCA may have some effect on the intake of plant nutrients, and that injury was actually the result of nutrient starvation.

Rebstock *et al* (3) found that wheat plants treated with TCA increased in nitrogen content and in content of arginine, reducing sugar and acid hydrolyzable polysaccharides. They found further that treated plants were decidedly lower in non-reducing sugars, ether extract, unsaponifiable material, and fatty acids.

The work reported in this paper is an attempt to throw more light on the nutrition of wheat plants as affected by TCA. Interest centers on whether or not the yellowing of the plants is caused by inability to assimilate nutrients, or whether the yellowing is the result of other physiological disturbances. If the latter is the case, changes in plant composition are the result of injury and subsequent failure to grow normally.

Materials and Methods

Oshtemo sand, 4,000 grams, was mixed with amounts of TCA corresponding to the rates of 15 or 30 pounds per acre and placed in No. 10 cans. The calculations were based on the surface area of the cans, and rates are expressed on an acid equivalent basis.

Each can received 500 ml. of distilled water initially. Frequent weighings were made, and each time, sufficient water was added to the cans to bring the moisture content to its original level. There was no loss because of leakage since the cans were water-tight.

Wheat was used as a test plant as it is known to have sensitivity to TCA at rates as low as 5 pounds per acre (2). The cultures were seeded to Henry spring wheat on March 9, 1951; 20 seeds were placed in each can at a depth of ½ to 1 inch.

The fertility level of the soil was raised by fertilizer, which was furnished by 1.6 grams of a mixture of ammonium sulphate, superphosphate, and muriate of potash, mixed in such a way as to make a 10–10–10 fertilizer. The mixture was added as a band application at the outer edge of the soil surface just prior to the date of sowing.

The crop was harvested on April 6, 1951, and the soil sample was taken by a specially designed soil sampling tube, which was inserted into the bottom of the can. The soil was analyzed for nitrate nitro-

gen, available phosphorus, and potassium by a revised Spurway method (5), and the pH of the soil was determined.

The plant tissue was analyzed for total nitrogen, using salicylic acid to reduce nitrates, and phosphorus, volumetrically after precipitation as ammonium phosphomolybdate, by methods given in Methods of Analysis, A.O.A.C. (1). Potassium was determined by the flame photometer, using lithium as internal standard. The data are given in Table 1.

RESULTS AND DISCUSSION

Fertilizers increased the NO_3, P, and K content of the control soil and total N and K content of the plants, but did not increase the phosphorus content of the plants (Table 1). Nitrates were increased to high levels on TCA treated soils, probably because of the fact that the demand by the plants was low, as a result of slow growth. This caused a considerable increase in the total nitrogen content of plants grown on TCA treated soil. The slow growth of the plants was probably the result of some interference in the metabolic activities within the plants. However, potassium in the plants did not increase when they were stunted by TCA treatments. On the contrary, there was a marked decrease which was intensified by an increase in amount of TCA applied. This indicates that potassium intake was depressed by the presence of the herbicide. One cannot conclude, however, that potassium starvation was surely the cause of the depressed growth, but there is some indication that it might be true. The evidence would be better, had phosphorus levels behaved in the same manner as did those of nitrogen.

Table 1. The effects of soil applications of TCA and fertilizer (10–10–10) on N, P, and K in wheat tissue and on pH, NO_3, P, and K contents of soil.

Treatments	Soil analysis				Plant analysis		
	ppm				Percent		
	pH	NO_3	P	K	N	P	K
C	6.3	2.8	0.6	4.2	2.75	0.492	2.00
CF	5.9	3.4	1.7	29.2	5.15	0.488	4.53
R_1	5.7	13.9	T	50.0	8.48	0.460	1.56
R_1F	5.5	19.5	1.2	50.5	9.55	0.593	1.86
R_2	5.7	15.3	B	26.5	9.03	0.528	0.90

Legend—C, no treatment; CF, fertilizer only; R_1, 15 pounds TCA per acre; R_1F, 15 pounds TCA per acre and fertilizer; R_2, 30 pounds TCA per acre; T, trace; B, blank.

Nutrient elements present in the soils are needed by the plant for building up plant tissues, protoplasm, and enzymes. Such enzyme systems in plants are built from proteins and nucleo-proteins and, thus, contain a large amount of nitrogen and phosphate with sulphur (4). It is very likely that these enzyme bodies cannot function properly, or at least, their effectiveness is greatly reduced in plants grown under toxic soil conditions.

Plant growth will take place when there are adequate supplies of cell building materials along with proper functioning of enzymes

and other growth regulating compounds (4). Perhaps unfavorable enzymatic activity and slow intake of potassium were complementary factors in bringing about the injury and slower growth.

In conclusion, it seems likely that the death of the TCA treated plants was not entirely the result of changes in the nutrient status of the soil, but rather, it was the result of a combination of physiological effects upon the metabolism of the plants.

SUMMARY

The toxic effects of soil applications of 15 and 30 pounds of TCA per acre, caused the death of wheat seedlings. Such lethal effect appears to result from metabolic changes accompanied by unbalanced nutrient intake.

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Fate and Activity of Herbicides in Soils[1]

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The fate of herbicides in the soil is of great importance to both research workers developing chemical weed control methods and to growers employing these newer techniques. It is desirable to know whether herbicides applied to the soil will persist and be cumulative so that subsequent crops will be affected, if a short period of residual activity can be expected, or if the compounds are rapidly dissipated. In case of pre-emergence applications where timing is critical and results vary with such factors as soil type, moisture and temperature, the activity and persistence of a herbicide are of great importance. Thus it seemed pertinent to study the effects of soil type, exchange capacity, temperature and amount of rainfall on breakdown, leaching and retention of certain herbicides in the soil. The herbicides used were 2,4–dichlorophenoxyacetic acid (2,4–D), N–1 naphthyl phthalmic acid (NPA), trichloroacetic acid (TCA), 3–(p–chlorophenyl)–1, 1–dimethylurea (CMU) and isopropyl N–(3–chlorophenyl) carbamate (CIPC).

Review of Literature

Persistence of 2,4–D under field conditions has been reported by different workers as varying from less than 10 days to 14 weeks (7, 8, 20). These variations in persistence are attributed to different soil types, rainfall, temperature, application rates, formulation, and possibly other factors.

Dissipation of 2,4–D in the soil under controlled conditions has been reported by many workers (4, 8, 11, 15) and has generally been attributed to microbial activity. Thus, environmental factors which affect microbial activity would indirectly affect 2,4–D breakdown. An increase in temperature has been shown to increase 2,4–D dissipation (4, 8, 11, 14). Similarly breakdown increases with an increase in soil moisture (4, 8, 11, 14, 15). Very little or no breakdown occurs in air dry soils (11, 14, 15). The addition to the soil of materials which increase microbial activity, such as manure (4) and leaf mold (15) favor the disappearance of 2,4–D. Conversely, autoclaving the soil increases persistence (4, 8, 11). Soil bacteria capable of decomposing 2,4–D have been isolated by Audus (1) and Jensen and Peterson (13).

The movement of 2,4–D through a soil profile has been shown by many workers (5, 7, 10, 11). The rate of movement or the amount of water required to remove various amounts of 2,4–D from the surface of various soils has apparently received less attention. Hanks (10) reported that different amounts of water were required to leach

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2,4–D through different soil types over a six week period, but there were no significant differences in limed or unlimed soil or with the calcium salt versus the acid. Crafts (5) found that relatively large amounts of water (80 to 320 surface centimeters) were required to remove 2,4–D from the soil surface and that it leached more readily in a sandy loam than in a clay loam. The effect of soil type was also studied by Hernandez and Warren (11) who found that 2,4–D leached more readily in soils low in organic matter than in soils high in organic matter. After thoroughly leaching a 2,4–D treated soil, Audus (1) noted that some 2,4–D was still present and its biological activity was comparable to that of a solution containing 1 p.p.m.

The persistence of TCA has been reported as ranging from 2 weeks to over a year (16, 22). Loustalot and Ferrer (16) found the dissipation of TCA to be increased by either an increase in temperature or soil moisture. They also reported that TCA persisted longer in a clay soil than in a sandy soil or sandy-clay mixture. Barrons and Hummer (2) reported that the rate of inactivation was greater in a soil high in organic matter than in one low in organic matter.

TCA appears to leach readily. Loustalot and Ferrer (16) stated that when ¼ inch of rainfall was applied to moist soil previously treated with TCA at 100 pounds per acre, the TCA moved down into the fourth inch of soil. When ½ or 1 inch of rainfall was applied, TCA moved down at least 8 inches in the soil. Both the leaching and persistence studies of Loustalot and Ferrer have been confirmed by Barrons and Hummer (2).

The persistence of isopropyl N-phenyl carbamate (IPC) has been reported under various conditions to range from 12 to 80 days (7, 18, 19). Newman, et al, (19) and Freed (9) reported IPC to persist longer in autoclaved soils than non-autoclaved, which would indicate microbial breakdown. DeRose (6) found CIPC to be very effective against germinating crabgrass seed. He compared the persistence of this compound with that of IPC and found that IPC persisted less than 24 days whereas CIPC persisted from 48 to 56 days. Stevens and Carlson (25) studying the breakdown of CIPC in the soil, reported a decrease in toxicity with an increase in temperature up to 75° F. Smith and Ennis (23) reported that CIPC was much less mobile in soils than 2,4–D.

Wolf (27) stated that at a rate of 40 pounds per acre CMU remained active for more than 18 months and suggested that its persistence might be affected by soil type, soil moisture, pH, and rainfall. At rates of 1 to 5 pounds per acre persistence ranged from 2 to 6 months.

MATERIALS AND METHODS

The sodium salts of 2,4–dichlorophenoxyacetic acid (2, 4–D), N–1 naphthyl phthalamic acid (NPA) and trichloroacetic acid (TCA), an 80 per cent wettable powder formulation of 3–(p–chlorophenyl)–1, 1–dimethylurea (CMU), and a 40 per cent liquid formulation of isopropyl N–(3–chlorophenyl) carbamate (CIPC) in a xylene carrier were used in the studies reported here.

Three Indiana soils with the following characteristics were used in these studies:

Soil type	Organic matter per cent	Exchange capacity	pH	Volume weight gm. per cc.
Princeton fine sand	1.0	3.0	5.7	1.54
Delphi silt loam	3.5	11.0	6.4	1.23
Muck	81.7	127.4	5.3	0.40

The muck soil had been farmed for over 15 years and consisted of finely divided organic particles. Organic matter was estimated by Schollenberger's oxidizable matter determination modified by Jackson (12). Exchange capacity expressed as milli-equivalents per 100 gram of oven dry soil was determined as outlined by Jackson (12). The pH was measured with a glass electrode. Volume weights were determined as outlined by Baver (3).

The activity of the herbicides in the soil was determined by a biological test. The method consisted of planting 50 crabgrass seeds *(Digitaria sanguinalis)* in the soil sample to be assayed growing these for a period of 2½ to 3 weeks, harvesting the tops and taking dry weights. Crabgrass was employed as a test plant since in the germinating stage it is susceptible to all the herbicides used. Subirrigation was practiced so that leaching was not a factor. A complete nutrient solution was added when needed so that nutrient deficiencies would not affect growth.

TEMPERATURE BREAKDOWN STUDIES

Studies were made to determine the effect of temperature on relative breakdown rates of herbicides in different soil types. NPA, CIPC, and TCA were applied at the rate of 8 pounds per acre. CMU and 2,4–D were applied at rates of 2 and 4 pounds per acre respectively. These rates are for pure material or acid equivalents and were chosen from field experience as approximately the minimum amounts that would give nearly complete kill of crabgrass in a silt loam soil. Calculations for the acre rates were based on the herbicide being distributed uniformly through 2 surface inches of soil. In muck soil, a preliminary experiment using NPA, 2,4–D, and CMU indicated that these rates would not be satisfactory for breakdown studies. Mixing the herbicides with the soil apparently increased absorption, thereby dissipating the herbicidal effects. Therefore, it seemed desirable to double the rates of application on this soil type. Thus NPA, CIPC, and TCA were applied at the rate of 16 pounds per acre, and CMU and 2,4–D at 4 and 8 pounds per acre respectively.

The herbicides were mixed uniformly with the soils. The treated soils were placed in 9 inch Pyrex dishes and covered with glass panes which permitted aeration but conserved moisture. The dishes were then placed in temperature chambers at 8, 18, 25, and 35° C. The soils were maintained in moist condition throughout the course of the experiment.

Soil samples were removed periodically and relative breakdown rates determined biologically and in the case of NPA a chemical test was also employed. All tests were run in triplicate. Soil samples for the biological test were placed in cellophane cylinders 1 inch tall and 2⅝ inches in diameter which in turn were placed in open petri dishes allowing for sub-irrigation.

Results of these studies (Table 1) indicate that the rate of breakdown varies for the different herbicides used and is also greatly influenced by soil type.

Table 1. Time in weeks required for complete dissipation of five herbicides in three soils at four temperatures and per cent activity at the end of 12 weeks for those still active at this time.

Herbicide[1]	Fine sand				Silt loam				Muck			
	8°	18°	25°	35°	8°	18°	25°	35°	8°	18°	25°	35°
	Time in weeks required for dissipation											
2,4-D	12+	8	8	10	6	6	6	2	12	10	8	8
NPA	12+	12	10	8	8	6	6	4	12+	12	10	6
CIPC	12+	12+	12+	12+	12+	10	8	6	12+	10	10	6
TCA	12+	12+	12+	12+	12+	12+	12+	12+	12+	12	10	12
CMU	12+	12+	12+	12+	12+	12+	12+	12+	12	10	8	4
	Per cent herbicidal activity after 12 weeks											
2,4-D	20	——	——	——	——	——	——	——	——	—	—	—
NPA	37	——	——	——	——	——	——	——	22	—	—	—
CIPC	100	93	93	46	63	——	——	——	13	—	—	—
TCA	100	93	93	73	100	4	4	14	88	—	—	—
CMU	100	100	100	100	98	98	97	93	——	—	—	—

[1]NPA, CIPC, and TCA were applied to the fine sand and silt loam soils at the rate of 8 pounds per acre; CMU and 2,4-D were applied at 2 and 4 pounds per acre respectively. Rates were doubled for muck soil.

2,4–D. In general the disappearance of 2,4–D was proportional to the temperature. Breakdown was more rapid in silt loam than in sandy soil and most rapid in muck. In the preliminary experiment 2,4–D at the same rate (4 pounds per acre) disappeared rapidly in the muck soil, in 1 week at 18 and 25° and in 4 weeks at 8 and 35° C. Thus muck appears to dissipate or inactivate 2,4–D rapidly. When the rate was doubled (Table 1) longer periods of time were required for inactivation.

NPA. Breakdown of NPA was somewhat slower than that of 2,4–D and was proportional to the temperature. As with 2,4–D loss of activity was greater in silt loam than in sandy soil and greatest in muck. In the preliminary experiment, NPA at the same rate disappeared rapidly in muck, in one week at 25 and 35° and in two weeks at 8 and 18°. When the rate was doubled (Table 1) longer periods of time were required for complete dissipation.

A chemical assay for NPA was also conducted and was compared with the biological assay. NPA was determined colorimetrically with a Coleman Universal Spectrophotometer, Model 14, using Smith and Stone's technique (24). In the silt loam and sandy soils the results were essentially the same as those obtained with the

biological method. In the muck series color interference was encountered with the chemical test such that the chemical assay appeared to be unable to measure all NPA that was biologically active. Thus the chemical assay indicated a slightly faster dissipation rate than the biological assay.

TCA. In the sandy soil (Table 1) relatively little breakdown of TCA was observed, but that which did occur was proportional to the temperature. Much more breakdown occurred in the silt loam and especially in the muck. Again dissipation was a function of temperature.

CIPC. Table 1 indicates that very little CIPC breakdown took place in the sandy soil during the course of the experiment. Only at 35° was there any appreciable loss in activity. In the silt loam soil a considerable amount of breakdown did occur, but the herbicide was still very active at 8° at the end of the experiment. Breakdown in muck in which double rates were used was rather rapid at 35°, disappearing in 6 weeks just as in the silt loam. Ten weeks were required for inactivation at 18 and 25°, and most of the activity had gone at 8° after 12 weeks.

CMU. No loss in activity of CMU was observed in the sandy soil and only a slight amount in the silt loam throughout the course of the experiment (12 weeks). In the preliminary experiment with muck in which the same rate was used (2 pounds per acre) there was no herbicidal activity. When the double rate was employed (Table 1), growth of crabgrass was equivalent to 16 per cent of the control initially. The activity disappeared in 4, 8, 10, and 12 weeks at 35, 25, 18, and 8° respectively, the implication being that the muck apparently has a tremendous capacity for CMU inactivation and decomposition. The sandy and silt loam soils, on the other hand, exhibited practically no capacity for either over a 12-week period of time.

MOVEMENT OF HERBICIDES

Two types of herbicidal movement studies were carried out. A percolation study was designed to follow the movement of the herbicides through soil columns following the addition of a constant amount of water (2 surface inches). A leaching study was designed to determine the relative amounts of rainfall required to remove the herbicides from the surface of the 3 soil types. Four replications were employed in both studies. Herbicides were applied in solution or suspension to the soil surface. NPA, TCA, and CIPC were applied at the rate of 8 pounds per acre and CMU and 2,4–D at 2 and 4 pounds per acre respectively. Distilled water was used in both studies to simulate rainfall.

Percolation Studies. Cellophane cylinders 2⅝ inches in diameter and 15 inches tall were filled with soil moderately packed to simulate a well prepared seedbed and then saturated with water. The herbicides were applied to the soil surface. Six hours were allowed for any reaction with the soil. The columns were then leached with 2 surface inches of water. After 12 to 24 hours the columns were sliced.

Slices 1 inch in thickness were taken such that depths of 0, 1, 2, 4, 6, 8, and 10 inches could be assayed for herbicidal activity. The biological assay previously described was employed. Bank sand was sprinkled lightly over the seed so that no disturbance of the soil column segments was made. These segments were placed in petri dishes which allowed for sub-irrigation.

The results (Figures 1, 2, and 3) showed that TCA was very mobile. Its greatest concentration was not at the surface layer as was found with other herbicides but at 2, 4, and 6 inch levels for silt loam, muck, and sandy soils respectively.

NPA and 2,4–D were less mobile than TCA. Both were uniformly distributed through the sandy soil column with progressively less movement in the silt loam and muck soils. CMU moved still less and was affected similarly by soil type. CIPC was the most resistant to movement. Although it was present at the 1 inch level in the sandy soil, activity was observed only in the surface of the silt loam and muck soils.

Leaching Studies. The second series of herbicide movement studies were conducted to determine the relative amounts of rainfall that would be required to remove a given herbicide from the surface of a particular soil. The soils, herbicides, and standard rates used in previous studies were again employed.

Soil columns were prepared in glass cylinders 2¾ inches in diameter and 6 inches tall. The soil was moderately packed and water was added to saturate the soil. Chemicals were applied and 6 hours were allowed for any reaction with the soil. Columns were then leached with 0, 2, 4, 8, 12, and 16 surface inches of water. Each treatment was replicated 4 times. After the water had moved through the cylinder, 50 crabgrass seeds were planted on the surface and lightly covered with sand. Results were taken as previously indicated.

The data for the sandy soil (Figure 4) show that TCA and 2,4–D leached very rapidly and very similarly. Most of the toxicity moved out with 2 inches and all with 4 inches of water. CMU apparently leached very little. NPA and CIPC were intermediate both being quite resistant to leaching in this soil type.

Data for the silt loam series (Figure 5) indicate that TCA and 2,4–D again leached readily, although 2,4–D required more water (8 inches) for complete removal of toxicity. Movement of NPA appeared to be slightly greater and CIPC and CMU much greater than in the sandy soil. All CMU toxicity was gone with 16 surface inches of water.

In the muck series also (Figure 6) TCA was very mobile, all the toxicity disappearing with 4 surface inches of water. Movement of 2,4–D was greatly retarded, 16 inches being required to remove all toxicity. It was interesting to note that NPA behavior was very similar to that in the other soil types. Very little CIPC movement occurred. CMU movement appeared to be somewhat less than in the silt loam.

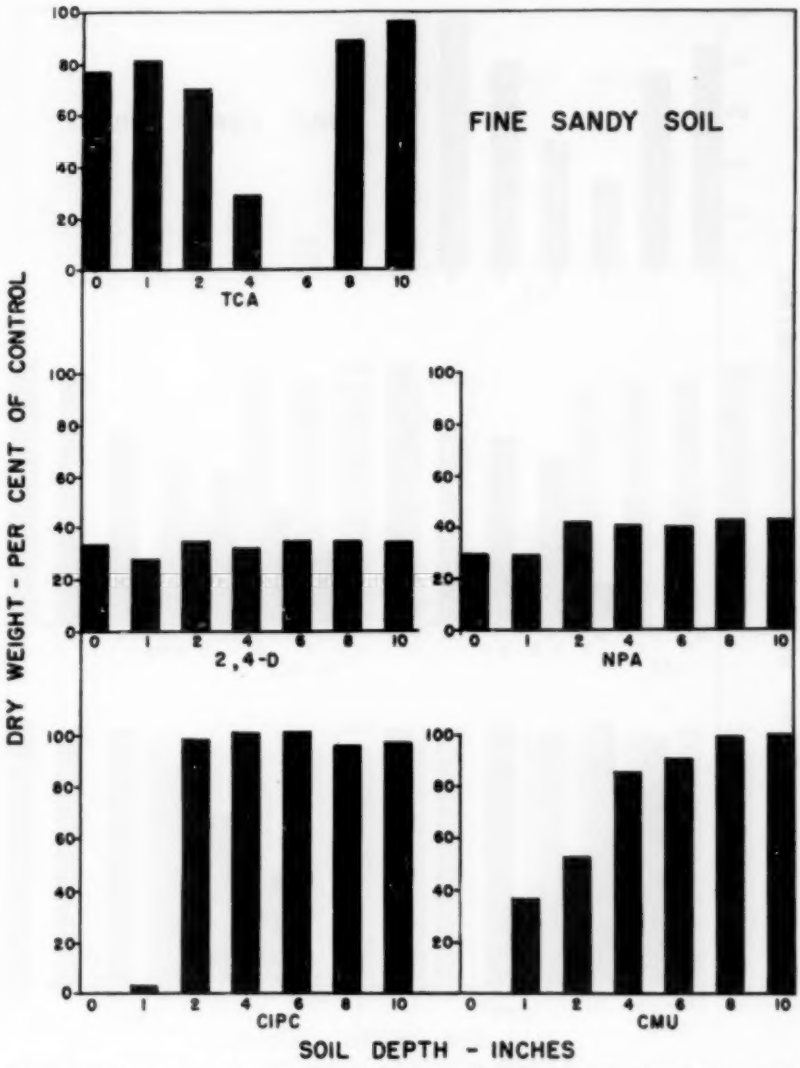

Figure 1. Movement of herbicides through a soil column, following application of 2 surface inches of water, as measured by crabgrass growth.

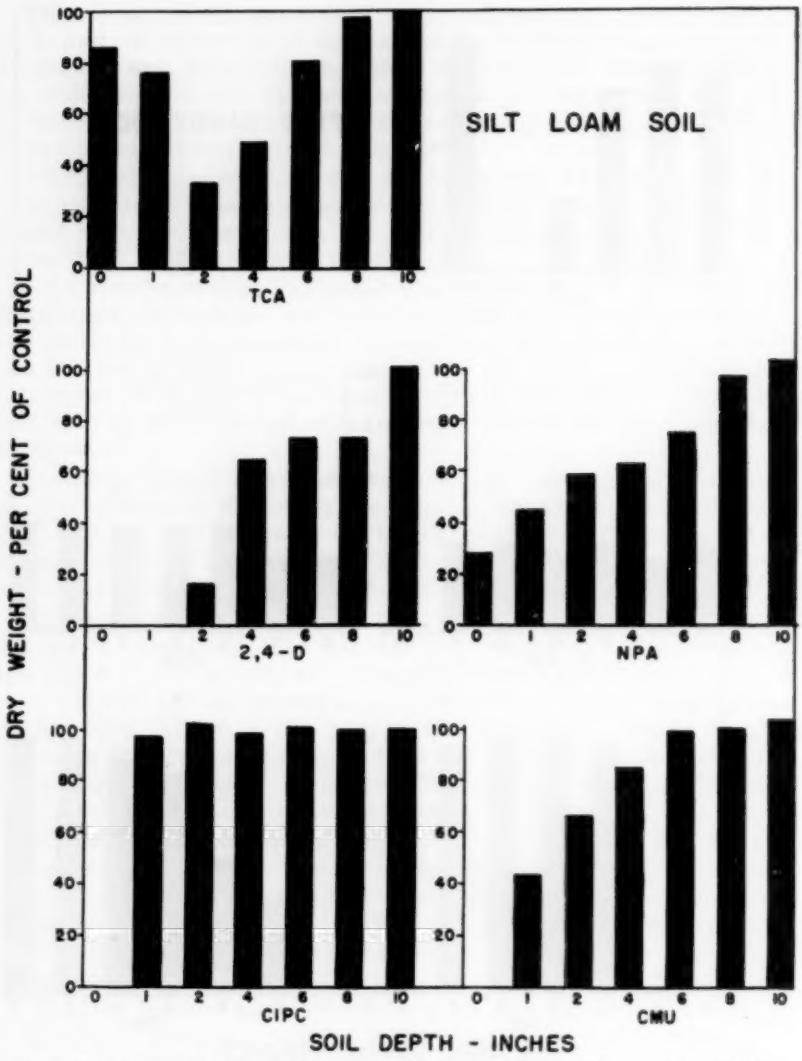

Figure 2. Movement of herbicides through a soil column, following application of 2 surface inches of water, as measured by crabgrass growth.

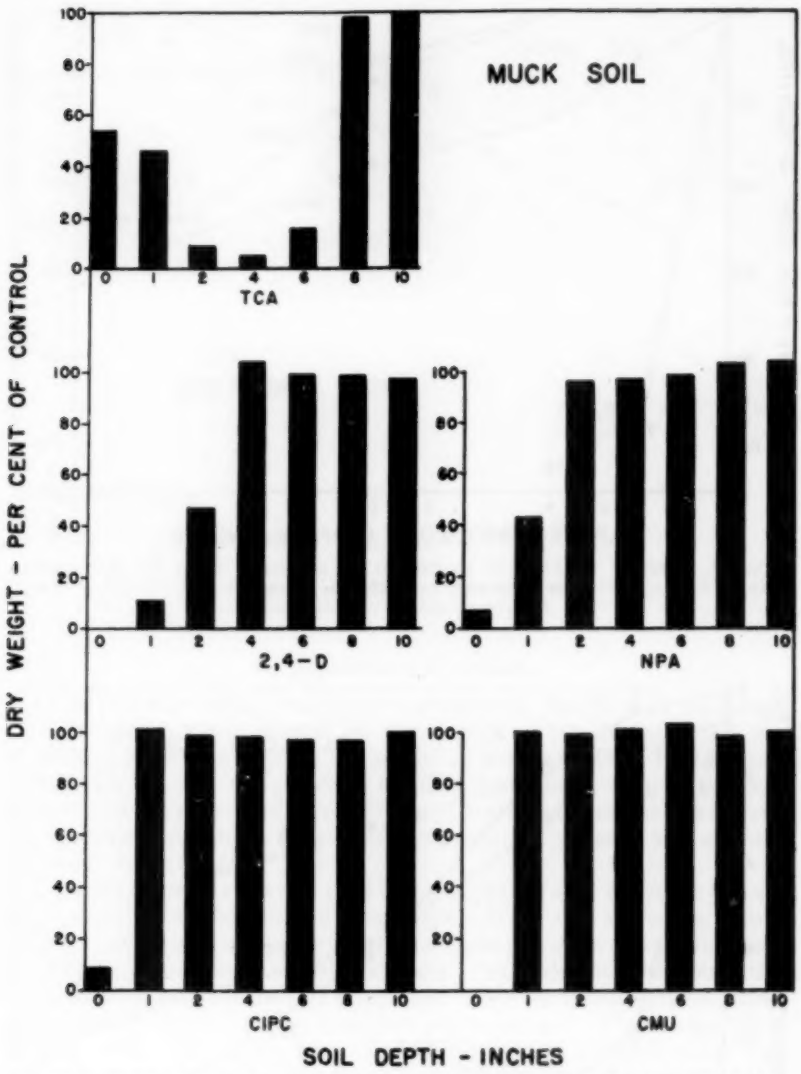

Figure 3. Movement of herbicides through a soil column, following application of 2 surface inches of water, as measured by crabgrass growth.

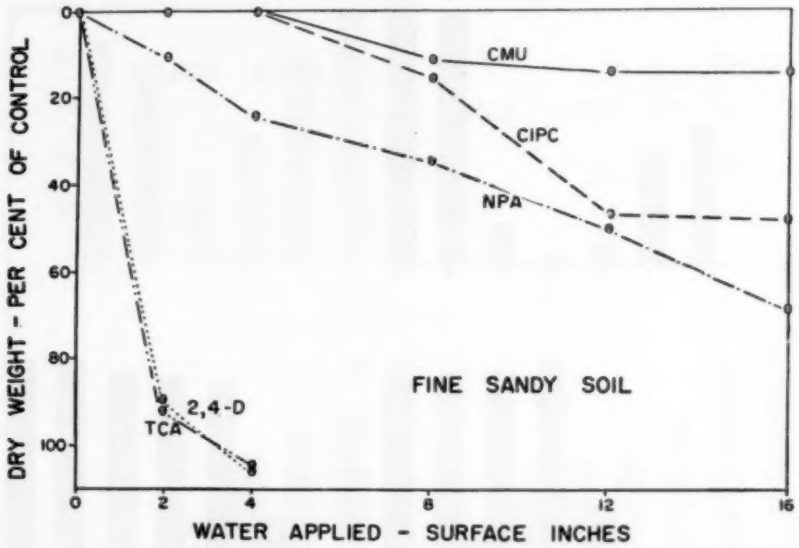

Figure 4. Effect of leaching on movement of herbicides from the soil surface as measured by crabgrass growth.

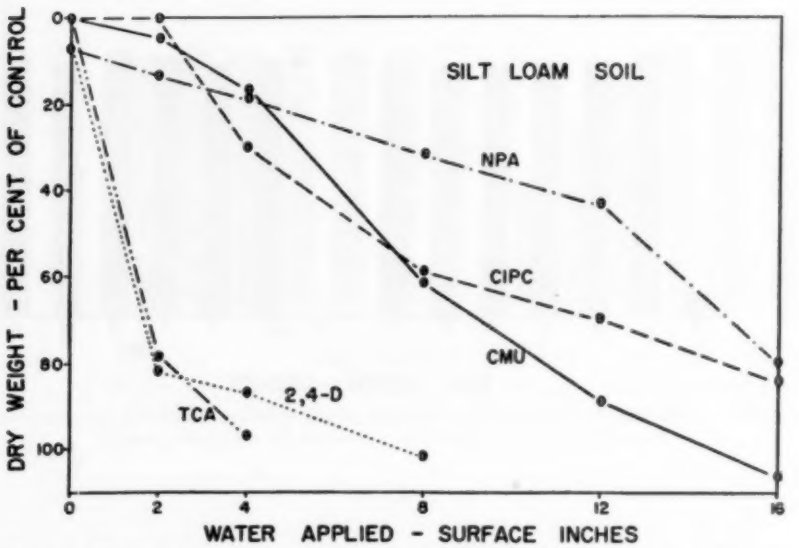

Figure 5. Effect of leaching on movement of herbicides from the soil surface as measured by crabgrass growth.

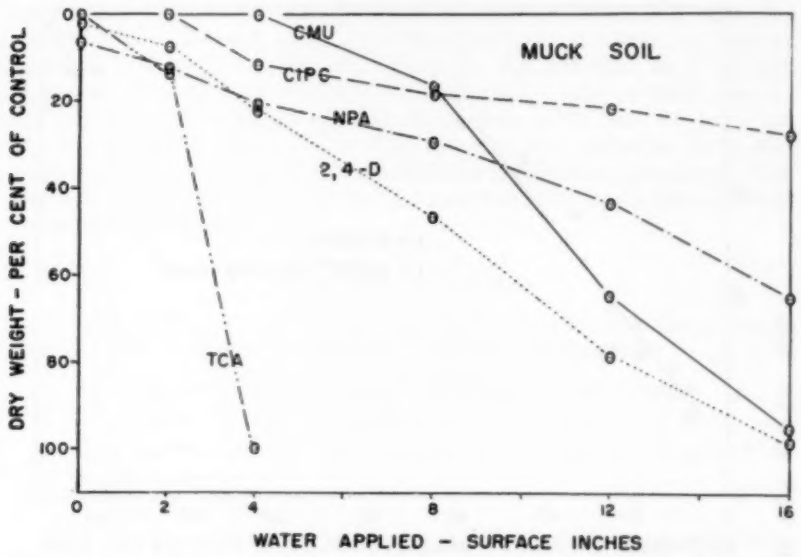

Figure 6. Effect of leaching on movement of herbicides from the soil surface as measured by crabgrass growth.

NPA Retention Studies

An experiment was carried out to determine the effect of exchange capacity and organic matter on the degree to which field soils are capable of retaining a given herbicide, in this case NPA. In addition to the soils used in the previous studies, 9 others varying in organic matter and clay content were obtained from the Purdue Soil Testing Laboratory. These soils were analyzed for organic matter and exchange capacity (12).

A 2 inch layer of each soil (176 cc.) was placed in a Buchner funnel fitted with Whatman No. 42 filter paper. NPA was added in dilute solution (10 ppm.) at the rate of 8 pounds per acre (6.1 milligrams per 176 cc. of soil) and additional water was added to distribute the NPA throughout the soil. The treated soils were allowed to stand overnight to allow for any reaction with the soil. They were then leached with the equivalent of 5.67 inches of rainfall, and the amount of NPA in the leachates was determined chemically (24). The amount retained was obtained by subtraction.

Amounts retained by each soil were plotted against both exchange capacity and organic matter content (see Figure 7). Correlation coefficients were determined for each, both with and without the muck soil. All are highly significant, with those obtained using exchange capacity being higher than the corresponding values using organic matter content. One could conclude from these values that exchange capacity would be a better measure of NPA retention than organic matter content. It was interesting to note that the amount

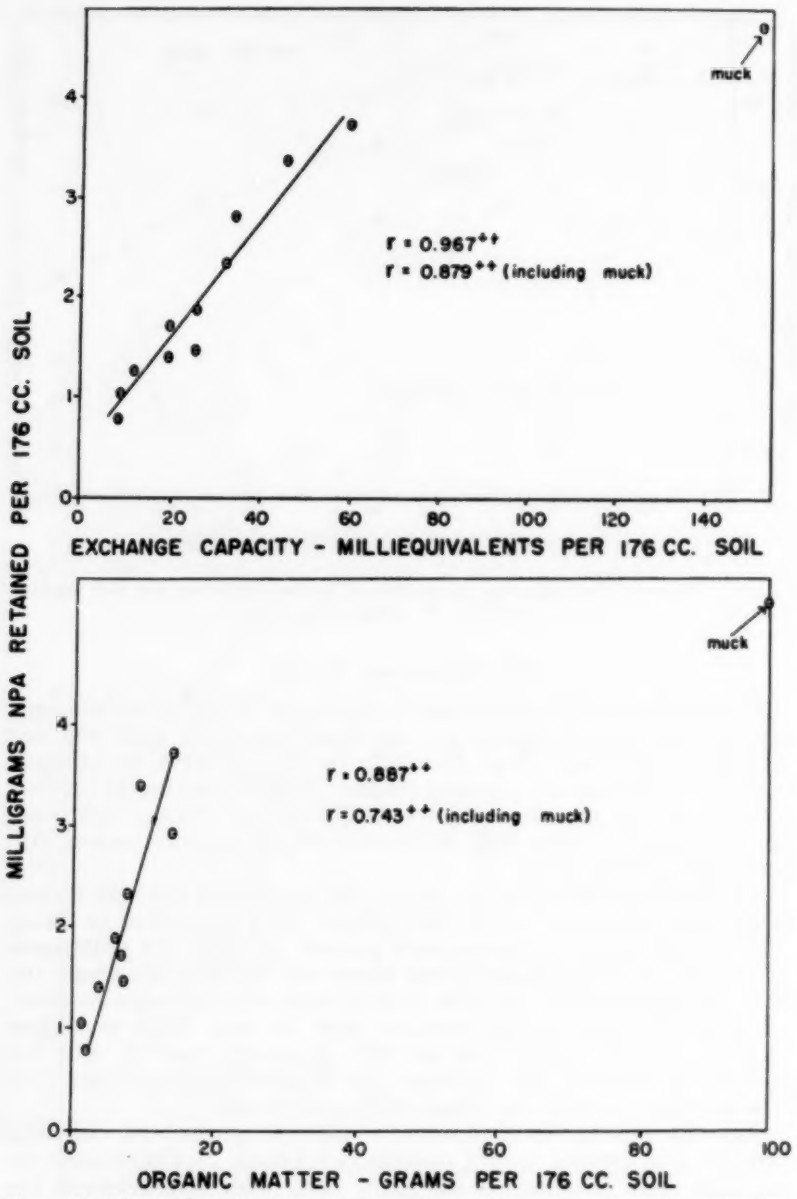
MILLIGRAMS NPA RETAINED PER 176 CC. SOIL
EXCHANGE CAPACITY - MILLIEQUIVALENTS PER 176 CC. SOIL
r = 0.967++
r = 0.879++ (including muck)
muck
ORGANIC MATTER - GRAMS PER 176 CC. SOIL
r = 0.887++
r = 0.743++ (including muck)
muck

Figure 7. Effect of exchange capacity and organic matter on NPA retention by 12 soils.

retained by muck was not in a straight line relationship with the mineral soils plotted against either exchange capacity or organic matter. The writers are unable to fully explain this. It is known, however, that cations are held less tightly by humus than by clay colloids (17). It is suggested, therefore, that NPA may be held less tightly by the muck colloids than by the clay colloids. It is also suggested, on the basis of the correlation coefficients presented, that the role of organic matter in NPA retention may be its contribution to exchange capacity.

DISCUSSION OF RESULTS

Results of these studies along with those of other workers indicate that the fate of herbicides applied to the soil is fourfold:

1. Breakdown, either microbial or chemical, may occur.
2. The herbicide may be leached out of the soil.
3. The herbicide may be retained in the soil in an active or inactive form.
4. Volatilization from the soil.

The effectiveness of herbicides applied to the soil is obviously dependent upon these factors. In this investigation breakdown, leaching and retention were studied.

Breakdown: Evidence obtained by many workers indicate that biological activity plays a major role in herbicidal inactivation. Therefore, environmental factors affecting biological activity would be expected to influence herbicidal decomposition. Thus, an increase in temperature in the studies reported here generally increased the rate of breakdown.

The effect of soil type on relative breakdown rates was very pronounced. Inactivation was least in the sandy soil, intermediate in silt loam, and greatest in muck (when applied at equal rates). The effect of soil type could be attributed to organic matter content and/or microbial population, the practical implication being that less residual activity can be expected in high organic soils than in lower organic ones if the same rates of application are employed. Other workers have reported greater dissipation with an increase in organic matter for 2,4–D (4, 15), TCA (2), and CIPC (25).

Herbicides apparently vary in their resistance to breakdown, but this resistance is affected by the factors indicated above. CMU and TCA were very resistant to breakdown in the sandy and silt loam soils, but were readily inactivated in the muck. On the other hand, 2,4–D was readily broken down in all soil types, the rate increasing progressively from the sandy soil to silt loam to muck. CIPC and NPA were intermediate in their resistance to breakdown, CIPC being somewhat more resistant especially in sand.

Movement: Obvious criteria for predicting the degree to which a herbicide will leach would appear to be the molecular size and the solubility of the herbicide and salts likely to be formed in the soil. Although these may be factors, results of the studies reported here

indicate that movement of herbicides in the soil cannot be predicted on a basis of their solubilities and molecular size alone. Many pre-emergence herbicides have been selected, perhaps empirically, on a basis of residual activity implying soil retention or resistance to leaching.

Some herbicides are apparently not retained or retained to a very limited extent by the soil. TCA appears to be such a herbicide, as it was observed to leach very readily, and if any was retained, it was not biologically active. Soil type appeared to have little effect on its movement. This rapid movement of TCA is in agreement with data of other workers (2, 16). A practical implication of these results is that as a pre-emergence treatment depth of planting would be of little protective value against injury from TCA in any of the soil types used in these studies. Neither could long residual control be expected in a humid region. However, it should be pointed out that since breakdown in the mineral soils was very slow, quite a long residual effect might be expected in arid and semi-arid regions.

The data reported here indicate that as with TCA, 2,4–D leaches very rapidly in a sandy soil. Although it also leaches readily in silt loan, the data suggest that a small amount which is still leachable with additional water is retained in an active form. In the muck quite different results were obtained. The 2,4–D is retained in active form so firmly that 16 inches of water were required to free the surface of all toxicity. These data indicate that of the soils studied only muck affords protection against 2,4–D for deeply planted seeds. Protection would, of course, vary with rainfall. This explains why growers are able to use 2,4–D on muck as a pre-emergence spray for onions, which are very susceptible to this herbicide (26).

CMU, which was quite resistant to leaching in the percolation study, represents a third type of herbicidal behavior with reference to movement in the soil. In the sandy soil after 16 surface inches of water had been applied, CMU was still present in the surface in a highly toxic concentration. Since it is soluble up to 230 ppm, 16 surface inches of water would be capable of dissolving 400 times the amount applied. Therefore, it would seem logical to assume that it was being held by the soil in an active form. Soil type was a factor since the CMU activity was greatly reduced in the silt loam and muck soils after large amounts of water had been applied. It is not reasonable to believe that more leaching had occurred in these soils (probably less in view of the percolation study) but rather that these soils were capable of inactivating part of the applied CMU. The capacity of muck to inactivate this herbicide was pointed out in the breakdown studies where it was mixed with the soil. These results are in agreement with those of Ries and Sweet (21) who reported less crop injury from a pre-emergence treatment of CMU as organic matter was increased, and indicate that deep planting would afford considerable crop protection in organic soils.

Still another type of herbicidal behavior in the soil is shown by CIPC. Results of the percolation and leaching experiments indicated that of the herbicides tested CIPC was the most resistant to move-

ment. Important implications of these studies are that deep planting should give considerable depth protection from CIPC when used as a pre-emergence treatment and that it should be highly resistant to loss by leaching.

NPA movement and retention in the soil could be considered intermediate and varied with soil type. Data from the percolation study showed that it was highly mobile in the sandy soil, less so in the silt loam and least mobile in the muck. On the other hand, its activity was not completely removed in any of the soil types by leaching with 16 inches of water. These data would indicate a lack of depth protection to crop seedlings on the mineral soils yet good retention of activity in the surface following heavy rains.

These results emphasize that there is an interaction between herbicidal movement and soil types. Therefore, one cannot predict herbicidal behavior in other soils from studies in only one soil. Similarly movement of other herbicides cannot be predicted from the performance of one herbicide in several soil types. Furthermore, these studies have indicated that more than one type of study is necessary to gain an insight into a complete picture of herbicidal movement in soils.

SUMMARY

The fate and activity of 5 herbicides (2,4–D, TCA, NPA, CIPC, and CMU) in 3 soil types were studied. Breakdown, percolation, leaching and retention experiments were conducted.

The following results were obtained:

1. In general herbicidal breakdown was found to be proportional to the temperature as would be expected in microbial decomposition. Soil type had a profound effect on breakdown, the rate increasing progressively from the sandy soil to silt loam to muck. Organic matter was believed to be responsible, at least in part, for this effect of soil type. Herbicides varied greatly in their resistance to breakdown. In general, CMU was most persistant followed in order by TCA, CIPC, NPA, and 2,4–D.

2. There was an interaction of herbicides and soil types in relation to herbicidal movement and retention. TCA moved rapidly in all 3 soil types; 2,4–D also leached readily in the mineral soils but was resistant to movement in the muck. NPA moved fairly readily in the sandy soil, was somewhat resistant to movement in the silt loam, more resistant in the muck, but was retained to a considerable extent in active form in the surface of all 3 soils. CMU was resistant to movement especially in the muck soil, and CIPC was highly resistant to movement in all 3 soils.

3. The capacity of muck to inactivate herbicides such as CMU was demonstrated.

4. There was a highly significant correlation between retention of NPA by mineral soils and exchange capacity, and a somewhat smaller but still highly significant correlation with organic matter content.

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Uptake, Distribution, and Metabolism of Carbon–14 Labeled Trichloroacetate in Corn and Pea Plants

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The action of trichloroacetate, a herbicide of grass-type plants such as quack grass and Johnson grass, has been studied for several years by observing the morphological responses of treated plants. Its presence in such plants has been indicated by analyses for the trichloromethyl group with a colorimetric test using pyridine and sodium hydroxide (1, 10). A review by Barrons and Hummer (1) indicates that root absorption is a much more important avenue of entry than foliar absorption. They also report differences in TCA content in the expressed sap of several species of treated plants. At 20 lbs. per acre they found "very little" TCA in corn and beans (both TCA-susceptible). At 10 lbs. per acre, they found "not a trace of TCA" in corn, "very little" in beans, but "a relatively high concentration of TCA" in peas (a relatively TCA-tolerant plant). However, Tibbitts and Holm (10) found 100 to 500 μg. of TCA per g. of fresh snap bean tissue from plants whose culture solutions contained 15 mg. of commercial grade 80% TCA as sodium salt per 150 ml. of nutrient. In order to check these observations, and to see whether TCA itself is present in the plants, and if so to determine the pattern of its distribution within the plants, as well as to look for possible metabolic products, C^{14}-labeled TCA was synthesized and used in tracer experiments with corn and pea plants.

Materials and Methods

Preparation and Purification of $C^{14}Cl_3COOH$

The starting material for the synthesis was one millimol of $C^{14}H_3COONa$[1]. This was converted to $C^{14}H_3COOH$ on a vacuum manifold (3) and was then passed through a silica gel column in a chloroform butanol solvent (7) to remove 0.8% of non-radioactive propionic acid. The C^{14}-acetic acid together with chlorine and acetic anhydride (9) was then distilled via a vacuum manifold into the tip of a Pyrex finger projecting down from a Pyrex bulb. This reactor was then isolated from the manifold by a stopcock. The reactants in the tip of the finger were heated at 50–70° C. for 234 hours while being illuminated by a mercury vapor sunlamp (G.E. S–4). Dumas (4) reported preparation of TCA by photochlorination. To avoid vapor phase reaction, which on early inactive runs had led to considerable amounts of by-products, the light as well as the heat was confined to the finger tip. Upon cooling the finger to room temperature at the end of the chlorination period, the material in it

[1]Purchased from Tracerlab, Inc., Boston, Mass.

solidified. Similar products of several inactive runs were identified by infrared analysis as TCA containing some dichloroacetic and monochloroacetic acids.

As a first step in the purification, the product was extracted into carbon disulfide. After removing the carbon disulfide under vacuum, the TCA was taken up in water and further purified by passing it through Dowex 50 resin (acid form) acting as an ion exclusion column (13). Pooling of the best three cuts flowing from this column gave TCA of about 98% radio-purity as estimated by autoradiochromatography. Three trace impurities were found.

PLANT GROWING CONDITIONS

Corn (Kingscrost) and peas (Perfection) were germinated in sand at 30° C. for 3–6 days and then grown one week with roots immersed in a mineral nutrient solution as described by Shive and Robbins (8) with added A–Z solution of Hoagland and Snyder (6). Plants were kept on a shelf 30 cm. below two 20 watt fluorescent lights (one white, one daylight) operated eight hours a day. At the end of this preparatory period the corn plants averaged 20–25 cm. in height with 3–4 leaves showing (not counting coleoptile). Pea plants were 7–11 cm. high.

TREATMENTS

The plants used to study uptake (via roots) and translocation or metabolism of TCA were transferred to fresh mineral nutrient solution to which had been added NaC^{14}–TCA to 34 ppm or 1.84×10^{-4}M. This concentration was chosen to approximate a field treatment of about 11 lbs. per acre with three inch penetration and 50% soil moisture. Corn shows significant morphological changes at four lbs. per acre (1). Other growing conditions were the same as in the pretreatment period.

A corn plant and two pea plants were harvested immediately after 3 days in the NaC^{14}–TCA solution. This treatment gives a slight stunting of the corn, but no noticeable effect on the peas. Another corn plant was harvested after a 15 day treatment. This had limited its height increase during that time to 50% of that of an untreated control. A third corn plant was treated 3 days and then returned to plain nutrient for 1 week before harvest. All leaf blades were removed from another corn plant prior to a 3 day treatment. These were all used to study TCA distribution within the plants. One corn and one pea plant were harvested after 3 days to look for metabolic products.

One corn plant was used to test for uptake and translocation by foliar absorption. It was first transferred to fresh mineral nutrient, then the outer half of the 3rd leaf blade was dipped for 2 minutes in a 2% aqueous NaC^{14}–TCA solution with 0.1% Triton × 155 (Rohm and Haas) added as a wetting agent. The leaf was then drained and the plant held 24 hours before harvesting.

ANALYSES

At the end of the treatment period the plants were removed from the nutrient, and the roots (also the dipped blade of the corn plant receiving the foliar application) were rinsed with distilled water and blotted dry. The plants were then dissected into various fractions as given in Tables 1 and 2. These fractions were each cut up into pieces about 0.5 cm. long.

For the uptake and translocation experiments the pieces from each fraction were placed in a small tared aluminum dish in a desiccator which was then evacuated. After drying and weighing they were oxidized to convert the carbon to CO_2. This was done by an adaptation of the wet combustion method of Van Slyke and Folch (11, 12). One sixth of a millimole of this $C^{14}O_2$ was distilled into a Geiger-Mueller tube, and the radioactivity from the C^{14} determined by the method of Eidinoff (5). Sample activities ranged from 6 cpm to 2000 cpm above background. By comparison with determinations of activity from C^{14}–TCA standards, these data were converted to ppm dry weight of plant parts.

For the metabolism studies, the juice from each fraction was expressed onto a small spot along one edge of a sheet of Whatman #1 filter paper by squeezing it, a piece at a time, between the paper, backed by a glass plate, and a glass cylinder. Spots of standard C^{14}–TCA were included in the series. After air drying, the paper was hung in a cabinet and developed as a one dimensional descending chromatogram using the organic phase of a 1–1 v/v mixture of 1–pentanol with 5 M formic acid (2). The completed chromatograms, after air drying, were sprayed with bromphenol blue indicator (2), and were then placed against Eastman Type K Industrial X-ray film. After 91 days of exposure, the films were developed.

RESULTS

TCA itself, but no metabolic breakdown products, was found in a corn and a pea plant. For, with a single exception, the only activity found on the chromatograms of juices expressed from their roots, stems, and leaves, was in spots corresponding in position to the standard TCA spots run on the same papers. The exception was a minute amount of activity in some of the pea juices corresponding in location to that of one of three trace impurities in the standard TCA. The indicator spray showed at least five non-radioactive acids on the chromatograms.

The distribution of TCA within corn and pea plants treated with TCA under several conditions is presented in Tables 1 and 2. There was uptake of TCA by a foliage-treated plant. The amount, however, was small compared to the quantity applied. In comparison much more was taken in by the root-treated plants. Tops and roots of the three day-treated corn plant contained 70–75% as much TCA as those of similarly treated pea plants. However, the shoot apex region of the former contained only 30% as much as that of the latter.

SUMMARY

NaC^{14}–trichloroacetate (NaTCA) was synthesized and used in tracer experiments with corn (susceptible to TCA injury) and pea (relatively tolerant to TCA) plants. The presence of TCA itself in TCA-treated corn and pea plants was confirmed by autoradiograms of paper chromatograms of the expressed juice of roots, stems, and leaves. No metabolic derivatives were found. The uptake and distribution of TCA in several corn and pea plants was determined by measurement of C^{14} radioactivity.

Table 1. Distribution of trichloroacetate in corn plants treated with NaC^{14}–trichloroacetate, based on radioactivity found.

Given as ppm dry weight of plant tissue.

Fractions	Root application 34 ppm in nutrient solution				Foliar application
	3 day treatment			15 day treatment	
	Immediate harvest	Delayed harvest	Debladed		
Root	734 (74)**	282 (20)	754 (99)	974 (122)	94*
1st node	340	—	274	—	—
Shoot apex	128	—	170	1286	122
1st leaf sheath	620	—	142	—	241
1st leaf blade	429	—	—	—	34
2nd leaf sheath	526	700	135	2460	—
2nd leaf blade	690	638	—	2240	—
3rd leaf sheath	316	—	161	—	128
3rd leaf blade	786	—	—	—	10,680† 996††
4th leaf sheath	258	547	—	1125	135
4th leaf blade	805	566	—	3000	160
Youngest leaf	198	—	122	888	162

*0.1 ppm of trichloroacetate was found in the residual nutrient solution.
**Figures in parentheses give ppm on a wet weight basis.
†Treated portion of leaf: Dipped in 20,000 ppm solution.
††Portion of leaf adjacent to treated portion.

Table 2. Distribution of trichloroacetate in pea plants grown with roots in 34 ppm NaC^{14}–trichloroacetate 3 days; then harvested. Based on radio activity found. Results expressed in ppm dry weight of plant tissue.

Fractions	Plant A	Plant B
Root	1110	1005
1st three internodes of stem	560	—
1st three leaves	1060	—
4th and 5th internodes of stem	204	264
4th and 5th leaves	2000	585
Shoot apex	477	—
Old seed	66	—

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New Growth Regulating Compounds
IV. Selected Toloxyacetic Acids

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Introduction

During the course of investigation of the activity of some organic compounds selected for potential herbicidal effects (5), many candidates appeared to have activity equal to that of the standard 2,4–dichlorophenoxyacetic acid (2,4–D), while a few appeared to be more active. One of the latter was *p*–fluoro–*o*–toloxyacetic acid, which was first prepared by M. S. Newman (3).

Because of promising results obtained in preliminary tests of this growth-regulator, it was subjected to more thorough evaluation by a number of greenhouse and growth chamber tests. The particular compound which was used in the later studies was synthesized expressly for this purpose by the Pennsylvania Salt Co. and did not differ in activity from the original sample.

Although the primary objective of these tests was to reevaluate the activity of *p*–fluoro–*o*–toloxyacetic acid in comparison with 2,4–dichlorophenoxyacetic acid, comparisons with some other members of the *ortho* toloxy family containing halogens in the *para* position were also made to evaluate the effectiveness of these halogens as compared to fluorine. Unfortunately, since the iodo compound was not available, this series is incomplete.

Materials and Methods

The inhibitory activity of the growth-regulators was determined by several methods involving various crop species and different methods of application. The corn germination test (A), kidney-bean single oil (D) and aqueous (C) droplet tests as previously described (5) were used without modification. The cucumber test (B) of Ready and Grant (4) and an oats soil test (E) which was developed by Ready and first reported by Minarik (1) were also employed. In addition a test involving the application of 1 to 10 mg. of the growth-regulator in aqueous solution to soil in which squash seedlings (var. acorn) were growing was also employed (H). Treatment was made when the first true leaf had just fully expanded and the plant was from 4 to 6 inches in height, and the plants were harvested 7–10 days after treatment. Inhibition of fresh weight of new terminal growth was employed as the criterion of effectiveness.

Another soil test using wheat (var. Thorne) as a test plant and 6″ petri dishes as the culture vessels aided in the evaluation of effectiveness of the inhibition of germination and subsequent monocotyledon development (F). A solution equivalent to 1.7 lb./A, was poured directly on the soil. The rate was expressed on the basis of soil weight. Twenty-five seeds were planted in each dish and 3 dishes were used per treatment.

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An additional test was one in which an aqueous solution of the test substance was added to the soil in which established rice plants (var. Onson) 6 weeks old were growing (G). The rate was 5 or 10 mg per ½ gallon glazed pot or 3.5 or 7 lbs./A. and the measure of effectiveness was inhibition of fresh weight of tops.

A final method was the aqueous spray of bean seedlings (var. red kidney) as described by Minarik et al (2); the only variation was that the volume of solution used for spray was reduced to 2 ml. (I).

In all of the above tests regardless of criteria, the results are expressed in terms of per cent inhibition based on an untreated control which was included in each test.

RESULTS

Results of the tests appear in Table 1. Although these figures represent quantitative measurements of inhibitory activity it should be remembered that in biological data small differences in values are of such normal occurrence that these are not to be considered significant. Examination of these data make it quite evident that the activity of *p*–fluoro–*o*–toloxyacetic acid is essentially equal to or greater than that of 2,4–dichlorophenoxyacetic acid in all tests but two, and that it is the most active compound in this *o*–toloxyacetic acid series. Also that the order of effectiveness of the halogens in descending order is fluorine, bromine, and chlorine*. Exceptions occur in the case of corn, cucumbers, and kidney bean droplet tests where there seems to be no inherent difference, and in the case of wheat where the bromine derivative rated lower than the others. In the case of acorn squash where at each of four levels the bromine

Table 1. The inhibitory activity of selected plant growth-regulators as determined in nine different tests. Figures represent per cent inhibition produced by the compound when compared with the untreated control.

Test	Dosage rates	2,4-dichloro-phenoxyacetic acid	o-toloxyacetic acids		
			4-fluoro	4-chloro-	4-bromo-
A. Corn germination	1 ppm.	23	39	17	15
	10 ppm.	59	70	84	75
B. Cucumber germination	0.5 ppm.	85	87	76	76
	1.0 ppm.	86	86	82	83
C. Kidney bean water droplet	4 ¤/plant	39	12	15	5
D. Kidney bean oil droplet	5 ¤/plant	77	79	60	58
E. Oats—soil	5 mg./pot.	16	41	2	−13
F. Wheat germination—soil	0.3 mg./plate	61	78	52	16
G. Rice—irrigated	5 mg./pot.	21	21	10	—
	10 mg./pot.	26	38	13	—
H. Acorn squash—soil	1 mg./pot.	14	34	−30	62
	3 mg./pot.	24	74	17	84
	5 mg./pot.	76	79	33	81
	10 mg./pot.	80	91	59	87
I. Kidney bean aqueous spray	50 ¤/pot.	72	62	20	24
	100 ¤/pot.	64	90	36	36
Mean		51	61	34	49

*iodine not available.

compound seems to be better, the cause may well be in the realm of specificity.

As a result of these nine diversified tests, it would appear that the *p*–fluoro–*o*–toloxy acetic acid compound is not only the best one of the *p*–monohalogenated–*o*–toloxyacetic acid series tested, but that it is at least equal to 2,4–D for growth-inhibitory action. The other members of this series are generally inferior to 2,4–D except the para-bromo compound which is outstanding for its effect on acorn squash. Here is posed the question of possible specificity.

SUMMARY

While the iodo compound was not available for test, the most effective compound in the series of para–monohalogenated–*o*–toloxyacetic acids was the fluorine containing member.

Para–fluoro–*o*–toloxyacetic acid was at least equal in growth-inhibitory activity to 2,4–D when tested by nine different methods.

Acorn squash was more susceptible to 4–bromo–*o*–toloxyacetic acid than to 2,4–D, or the corresponding fluoro or chloro members of the toloxyacetic acid series.

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Effectiveness of Isopropyl N–(3–Chlorophenyl) Carbamate As a Selective Pre-Emergence Herbicide in Cotton[1, 2]

CHESTER L. FOY[3]

INTRODUCTION

ONE of the most important of the numerous difficulties involved in the successful production of cotton is that of controlling weeds. The fertile soils and humid seasons generally occurring in the Delta, provide optimum conditions for abundant weed growth. During 1951, Missouri cotton producers spent approximately $10,000,000 for hand-labor alone in the production of a $69,000,000 crop. With the exception of Johnson grass (*Sorghum halepense* L.) and some perennial vines, annual weeds (particularly grasses early in the season), are most troublesome. By far the worst offender under the conditions of the 1951 through 1953 experiments was crabgrass *(Digitaria sanguinalis L. (Scop.).*

With the presently low and ever decreasing labor supply, mechanization is not only desirable, but may become essential in order to produce cotton profitably. Weed control, along with harvesting, stands foremost among the last remaining barriers to complete mechanization of the crop.

Experiments in Missouri and elsewhere have shown that by the use of such relatively new agronomic practices as hill drop planting to a stand, cross plowing, application of pre-emergence and post-emergence chemicals, and flame cultivation, the cost of hand labor can be materially reduced below that of former methods. Research programs with herbicides in cotton have been widely expanded throughout the cotton belt in recent years. In 1952, for example, an estimated one-quarter million acres of cotton were "chemically hoed", and this figure is likely to show a rapid increase in the immediate future.

The objectives in Missouri are basically these: (1) reducing or eliminating hand labor from cotton production; and (2) finding a practice which provides a reasonable amount of insurance against crop failure due to early weed infestation. For these reasons, specifically the latter, most attention has been given to pre-emergence herbicides. The new agricultural chemical isopropyl N–(3–chlorophenyl) carbamate (CIPC) showed excellent promise for this use in 1952 and 1953, particularly against annual grasses.

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[1]The 1952 results are part of a thesis submitted in partial fulfillment of the degree of Master of Science, Department of Field Crops, University of Missouri, Columbia, Missouri, and 1953 results are a continuation of the project.

[2]The work reported herein was supported in part by a grant-in-aid from the Columbia-Southern Chemical Corporation of Pittsburgh, Pennsylvania.

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REVIEW OF LITERATURE

CIPC is one of the recent additions to the family of carbamates, typified earlier by the more familiar IPC. A voluminous literature concerning IPC exists, but few references relate to cotton. The early work in the United States with the carbamates was conducted by a group of investigators at Camp Detrick (19). Ennis (8) first demonstrated the tolerance of cotton to CIPC, in comparison with other crops, when the herbicide was applied to the soil. DeRose (5) first illustrated the possible value of CIPC for selective use against crabgrass. The first great promise for CIPC as a selective pre-emergence herbicide in cotton was shown by Leonard *et al.* (14) in 1949 in Mississippi. These experiments suggested extensive field use of CIPC as a pre-emergence herbicide in controlling crabgrass and other weeds in cotton. Differential responses by various species have been noticed by several workers, and many agree that best selective action against grasses has been obtained on loamy, productive soils, high in organic matter (3, 6, 21). The mode of CIPC toxicity is now known to be similar to that of IPC (5, 8, 9). DeRose (5) found evidence of CIPC's longer persistence in the soil, and Ennis (8) noticed the increased phytotoxicity due to the introduction of the chlorine atom to the IPC molecule. Other pertinent facts are also now known concerning the use of CIPC: Meristematic root tissue is most vulnerable (2, 11), therefore best results are obtained through soil application (4, 7); it is relatively immobile in the soil (18); adequate moisture is essential for effective control, however, heavy cool rains may leach toxic concentrations into the zone of germinating cotton and cause injury in certain cases (10, 13, 15). Moisture, temperature, soil type, fertility, soil microflora, and rate of application govern the persistence and final effectiveness of CIPC (6, 11, 16, 21). Recent field studies in several other states have shown much success in the pre-emergence use of CIPC in cotton (1, 12, 13, 15, 17, 20).

METHODS AND MATERIALS

A total of eighteen field experiments involving the use of CIPC in cotton were conducted in Southeast Missouri during 1952 and 1953 on a moderately fertile Lintonia sandy loam soil. Land preparation and fertilization were conventional for the area.

Planting on the level, and to a stand, was accomplished by use of a two-row tractor planter equipped with a hill drop attachment. In the pre-emergence tests the rows were rolled with 12-inch banded planter wheels or water filled drums of the same width, and the 12-inch bands directly over the row were sprayed immediately following. One exception was a test in which the type of press wheel used constituted the variable. Rates included in the table are expressed for overall coverage, even though only a 12-inch band over the row was actually treated.

Inexpensive spray equipment, and the field pattern resulting from its use in 1952 are shown (Figures 1 and 2). In 1953, the test plots

Figure 1. Equipment used in 1952 to hill drop plant, smooth a 12-inch band, and apply pre-emergence herbicides.

Figure 2. A good stand of hill dropped cotton where a 12-inch band over the row was sprayed with a pre-emergence herbicide simultaneously with planting.

were fertilized, hill drop planted to a stand, rolled, and sprayed with a pre-emergence herbicide all in one operation.

All pre-emergence materials were either dissolved, emulsified, or suspended in water, and applied in 40 gallons total volume per acre. For band treatment, this means 12 gallons per acre for cotton planted in 40-inch rows. All formulations of CIPC were emulsifiable concentrates. In another test not reported here, there was no essential difference in the performance of CIPC from 7 different commercial sources and formulations, as long as the amount of active ingredient was constant.

A Broyhill spray rig and power take-off mounted gear-type pump were used for most field trials. Nozzle sizes, operating speeds and pressures were varied slightly between experiments, but, in general, 8002 and 8003 Tee-Jet nozzles were used, and the rig was frequently checked for possible need of re-calibration.

Weed counts were taken over the entire length of the plots by use of a 10-point quadrat over the 12-inch bands. Fifty 10-point trials or 500 points were averaged and recorded. Tests were replicated 4 to 6 times, in accepted agronomic experimental designs. Cotton stand counts represented a 25 percent actual count. Hoeing time was actual for each plot considered and was converted to an acre basis. Hoeing costs were computed at $.50 per hour and the cost of chemicals as follows: CIPC—$10.95 per gallon (1952), $7.50 per gallon (1953); DNOSBP—$5.25 per gallon; CMU—$3.50 per pound. CIPC containing 4 pounds of active ingredient per gallon; DNOSBP, 3 pounds per gallon; and CMU as an 80 per cent wettable powder were the formulations used, and apply to all included tables.

All cultivation was conducted in such a manner as to prevent moving soil into the treated bands until such time as all notes were recorded or the chemicals had lost their effectiveness.

All tests were statistically analyzed; however, certain tables are grouped as two-year averages, in which case statistical indices are omitted.

RESULTS AND DISCUSSION

Influence of Planting Date and Weather Conditions on Chemical Action

First experiments with CIPC were made in comparison with dinitro–o–secondary butyl phenol (DNOSBP), which was the most widely used pre-emergence herbicide in cotton and considered to be the best standard for evaluation of new materials. To evaluate CIPC rapidly, under different weather conditions, the two chemicals were compared at equal rates (1952-by volume, 1953-by weight) over 5 dates of planting beginning the middle of April and spaced 10 days to 2 weeks apart throughout the planting season. Table 1 is a summary of 2 years' data, each year representing tests on 5 dates of planting.

Weed populations varied rather widely between dates of planting due to differences in temperature, soil moisture, and the number of ungerminated weed seeds remaining in the soil. Temperature was

Table 1. Weed control, attendant costs, and resulting yields of cotton following the use of certain pre-emergence herbicides. Weed counts and hoeing time were recorded 3–4 weeks after treatment. (Summary of 10 experiments 1952–1953).

Treatment	Rate lbs. per acre	Percentage weed coverage in 12 in. bands	Hoeing time hours per acre	Hoeing cost dollars per acre	Cost of chemical dollars per acre	Total cost dollars per acre	Yield of seed cotton lbs/acre
Check....	———	42.6	28.4	14.20	——	14.20	1585
DNOSBP	5.0–6.6	13.7	15.8	7.90	2.63	10.53	1610
CIPC.....	6.6	5.6	8.4	4.20	4.61	8.81	1633

found to have a direct effect on the behavior of CIPC. Vapors of CIPC were apparently non-toxic, whereas DNOSBP vapors reportedly accounted for considerable loss of cotton stands in 1952. Even though CIPC vapors were not injurious, loss of the chemical by volatilization became an important consideration, particularly when the temperatures were in excess of 90° F. immediately after treatment. Effectiveness of weed control appeared to be reduced proportionally to the loss of CIPC, as temperatures increased.

Although CIPC was not considered readily leachable in the soil, moisture was nevertheless important to move the chemical to the zone of germinating weed seeds for maximum effect. Less favorable results were always obtained when both the soil and air were hot and dry than when ample rainfall closely followed application. Best weed control was experienced in the early spring when it was most needed. Ample rainfall and cool soil and air temperatures, which normally occurred during this period, were both conducive to maximum retention and effect of the CIPC. Even under these conditions which sometimes stunt cotton plants directly, predispose them to fungus diseases, and render them more susceptible to chemicals, injury was rare when recommended rates of CIPC were employed. Regardless of weather fluctuations, both CIPC and DNOSBP provided significant weed control in every test for 3 to 7 weeks (Table 1). The tests were analyzed separately (not collectively), therefore statistical indices are not included. CIPC gave consistently higher percentages of weed control than equal rates (both by volume and weight) of DNOSBP. In many of the separate dates of planting the differences were statistically significant, and the trend was strongly evident throughout other dates of application.

Although early observations showed only small differences between DNOSBP and CIPC plots, later weed counts showed decided differences in the performances of the two chemicals (Table 1). This indicates that the toxic effect of DNOSBP was dissipated more quickly than that of CIPC. Percentage comparisons of weed control by each chemical are shown. Hoeing time and ultimate costs of weed control reflect a similar pattern. Although CIPC was more expensive than DNOSBP, it gave enough additional control so that when total costs were computed, CIPC was the most economical treatment. Control of crabgrass was satisfactory (Figures 3 and 4).

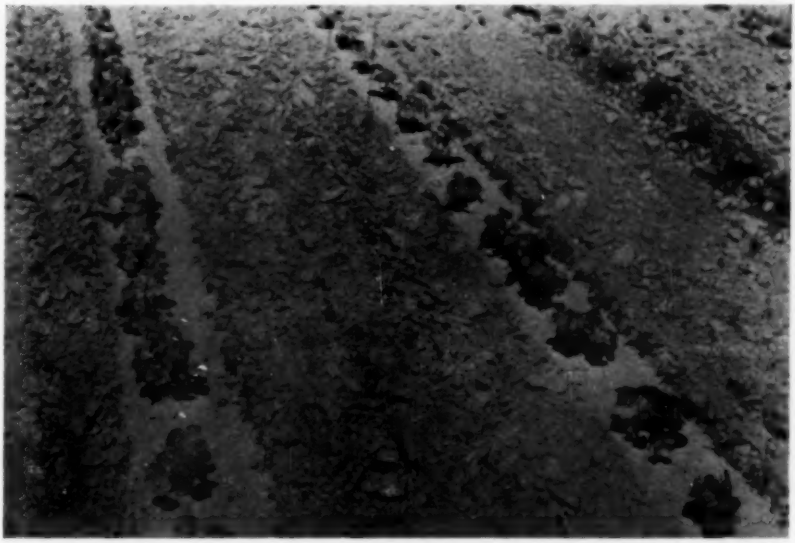

Figure 3. Control of weeds in cotton with 6.6 pounds per acre of CIPC, approximately 4 weeks after treatment. Middles were cleaned by a conventional cultivator with shields to protect the treated bands. Note grass just off the treated bands.

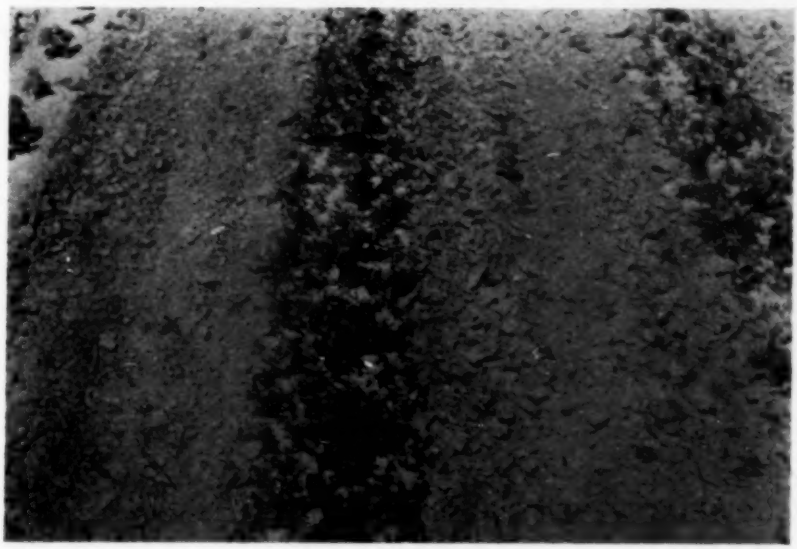

Figure 4. An untreated check plot showing profuse growth of weeds, primarily grasses, approximately 4 weeks after planting. The weeds were removed from the middles by conventional cultivation.

In two early plantings during cool weather, which were followed by heavy rains, CIPC caused cotton plants to exhibit injury symptoms during the early growth stages (Figure 5). The cotyledons were heavy, cupped, and split; the true leaves were crinkled, deformed, reduced in size and were darker green than normal. These symptoms were soon overcome and the plants were soon equal to, or surpassed, untreated plants.

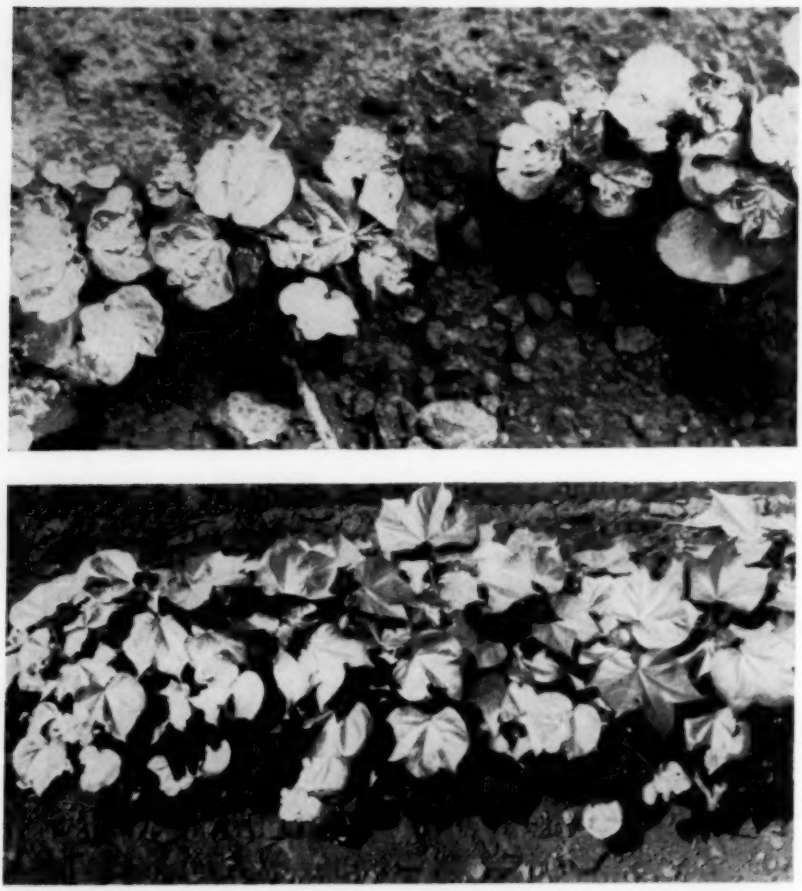

Figure 5. Cotton treated with 9 pounds of CIPC per acre, approximately 4–5 weeks after treatment (above), and 7 weeks after treatment (below). Note early injury symptoms were overcome in later growth.

In taking weed counts, certain differential responses were noted. CIPC gave more selective action for annual grasses in general, and for crabgrass specifically, while DNOSBP appeared to give better control of certain broadleaved weeds. Among the species which CIPC did not control effectively were Johnson grass *(Sorghum*

halepense L.), nutgrass *(Cyperus rotundus L.),* Carolina horsenettle *(Solanum carolinense L.),* and ragweed *(Ambrosia elatior L.).* Pigweed *(Amaranthus* spp.) was reasonably well controlled but less consistently than were the grasses.

Most crabgrass seedlings were suppressed below the ground, and those which did emerge were inhibited by CIPC such that they never developed beyond one-inch in height. The plants were poorly rooted and the root tips were short and swollen. Their poor anchorage was demonstrated by the fact that a gentle brush of the hand dislodged these plants from the soil. No such phenomenon occurred in the DNOSBP treated plots.

Effect of Press Wheel on Cotton Stand and Weed Control

There is presently some controversy as to the merits of a press wheel or smoothing device. One reason for the use of a roller is to provide a smooth area on which to apply the chemical sprays, whether pre- or post-emergence liquids, or to flame cultivate.

One test using CIPC under dry soil surface conditions showed no significant differences in weed control, cotton emergence, or yield, due to the type of planter press wheel used.

Effect of Rate of Chemical on Weeds and Cotton

Experiments to determine not only the most effective, but also the most economical rate of CIPC (when all costs are computed) have been conducted for 2 years. The 1953 results comparing CIPC, DNOSBP, and CMU (3–p–chlorophenyl–1, 1–dimethyl urea) are considered representative for this soil type (Tables 2 and 3).

The same differential responses between weedy species were apparent. Excellent control of crabgrass was achieved with all chemicals at first, but DNOSBP began losing its effect after 4 weeks. Species not effectively controlled after 6 weeks by CIPC were ragweed and horsenettle. Annual morning glory emerged, but was decidedly

Table 2. Effect of various pre-emergence herbicides on weed populations at 4, 6, and 8 weeks after planting, and on cotton stands. Cotton planted May 9 and stands recorded June 18, 1953.

Treatment	Rate lbs. per acre	Percentage weed coverage in 12 in. bands over row			Cotton plants per 100 ft. of row
		4 weeks after planting	6 weeks after planting	8 weeks after planting	
1. Check	—	74.2	—	—	109
2. DNOSBP	6	8.1	41.0	—	114
3. DNOSBP	9	2.9	24.7	—	109
4. DNOSBP	12	0.5	11.3	—	113
5. CIPC	6	1.8	11.8	—	120
6. CIPC	9	0.6	3.8	—	107
7. CIPC	12	0.4	2.3	15.5	108
8. CMU	1	0.1	0.4	5.2	123
9. CMU	1.5	0.0	0.5	4.3	112
10. CMU	2	0.0	0.2	2.5	108
L.S.D. at 5% level		2.8	9.4	4.0 not significant	
at 1% level		3.8	12.7	5.7	

Table 3. Effect of various pre-emergence herbicides on the cost of weed control and on yields of cotton.
Cotton planted May 9, 1953.

Treatment	Rate lbs. per acre	Hoeing time hours/acre			Hoeing cost dollars per acre	Cost of chemical dollars per acre	Total cost above culti. dollars per acre	Yield of lint cotton pounds per acre
		9 June	23 June	10 July				
1. Check	—	27.8	—	—	13.90	—	13.90	647
2. DNOSBP	6	—	10.0	—	5.00	3.15	8.15	581
3. DNOSBP	9	—	7.6	—	3.80	4.73	8.53	662
4. DNOSBP	12	—	5.4	—	2.70	6.30	9.00	609
5. CIPC	6	—	6.7	—	3.35	3.38	6.73	612
6. CIPC	9	—	4.6	—	2.30	5.06	7.36	634
7. CIPC	12	—	—	2.9	1.45	6.75	8.20	629
8. CMU.	1	—	—	2.7	1.35	1.31	2.66	682
9. CMU	1.5	—	—	2.3	1.15	1.97	3.12	629
10. CMU	2	—	—	2.1	1.05	2.63	3.68	499
L.S.D. at 5% level (all treatments)				1.6				64.7
at 1% level				2.2				88.5

stunted. Horsenettle was the most resistant species present, and was only slightly retarded by the high rate of CMU.

CIPC at rates of up to 12 pounds per acre did not injure the cotton. CMU gave decidedly the best control, but it was also the only chemical which produced injury symptoms at all rates tested. Cotton stands were not altered, but the yield was significantly reduced by the 2-pound rate of CMU. Optimum rates of CIPC for this soil type were in the range of 6 to 9 pounds per acre. It appeared that 1-pound of CMU per acre should be the upper limit for safety of the crop.

Should CMU or one of its derivatives be proven consistently safe enough for general use, it would be considerably less expensive than CIPC on a per-acre-of-cotton basis. No pre-emergence herbicide is known which will give complete control of all weeds incident to cotton production without causing some injury to cotton as well.

SUMMARY

1. In two years experimentation (18 tests), CIPC compared favorably with the best available pre-emergence herbicide used in cotton against annual grasses, particularly crabgrass, and against certain broad-leaved weeds. Its limitations were realized with respect to controlling established perennial pests, and certain resistant annuals.
2. The effectiveness and persistence of CIPC were influenced by many factors including temperature, moisture and rate of application. Highest herbicidal effectiveness was experienced under cool, moist conditions.
3. Optimum rates of CIPC for the given soil type were 6 to 9 pounds per acre.
4. The chemical had a long, residual action (6–8 weeks) for control of weeds during the season, yet allowed a wide margin of safety such that cotton yields were never reduced at rates as high as 12 pounds per acre.

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for January, February, and March 1954

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This bibliography of current literature on weeds and their control is issued as a service to those engaged in weed research in the United States and other countries. In issuing this bibliography the Section of Weed Investigations does not assume responsibility for the subject matter cited.

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